TEXTILE RESEARCH JOURNAL

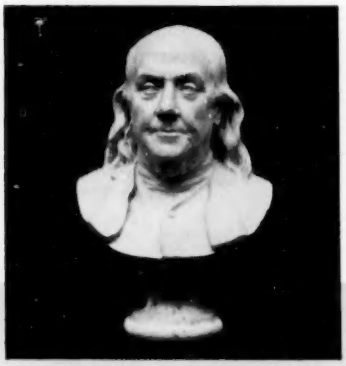
VOLUME XXVI September 1956 *NUMBER 9*

PUBLICATION OF

TEXTILE RESEARCH INSTITUTE

Publications Department: P. O. Box 625, Princeton, N. J.

onyx



Courtesy of The Metropolitan Museum of Art

"An electrified body left in the room for some time will be covered more with dust than other bodies in the same room not electrified, which dust seems to be attracted from the circumambient air." *

Benjamin Franklin,

Memoirs of the Literary and Philosophical Society of Manchester, 1785

The Onyx Oil & Chemical Company announces a new product of its Research and Development Laboratory:

*ASTON LT

A NEW CONCEPT OF CHEMICAL PROTECTION AGAINST ACCUMULATION OF STATIC CHARGES BY TEXTILES

ASTON LT (LT for "lifetime") provides anti-static protection for the fabric and the garment for the useful life of the garment regardless of how often it is washed or dry-cleaned.

Every type of synthetic fiber can be finished efficiently with ASTON LT: nylon and other polyamides; Dacron and other polyesters; Orlon and other acrylics; Dynel and other vinyls, as well as Arnel triacetate fiber. ASTON LT is easy and economical to apply.

By surrounding every fiber with an invisible sheath, ASTON LT gives the surface the properties of a hydrophilic fiber. The hydrophobic core of the fiber under the protective layer retains its valuable functional properties. Thus, fibers that are ASTONIZED, permanently combine the desirable properties of both types of fibers—the comfort, absorbency and resistance to static build-up of the natural fibers, and the strength, dimensional stability and crease-resistance of the synthetic.

The development of ASTON LT opens entirely new opportunities in textile finishing and applications.

TEXTILE DIVISION

ONYX OIL & CHEMICAL COMPANY

WARREN & MORRIS STS., JERSEY CITY 2, N. J.

Export: ONYX INTERNATIONAL • Jersey City 2, N. J.

ATLANTA
BOSTON
CHARLOTTE
CHICAGO
LOS ANGELES

TEXTILE RESEARCH JOURNAL

VOL. XXVI, No. 9 SEPTEMBER 1956

IN THIS ISSUE

THE RELATIONSHIP BETWEEN THE STRUCTURAL GEOMETRY OF A TEXTILE FABRIC AND ITS PHYSICAL PROPERTIES. *PART VI:* NOMOGRAPHIC SOLUTION OF THE GEOMETRIC RELATIONSHIPS IN CLOTH GEOMETRY. Douglas P. Adams, Edward R. Schwarz, and Stanley Backer 653

A FIBER LENGTH TESTER WITH AUTOMATIC PUNCHED-CARD REGISTRATION. J. H. Wakelin, H. W. Lambert, and D. J. Montgomery . 665

PHYSICAL PROPERTIES OF COTTON REACTED WITH BETA-PROPIOLACTONE. Emilie H. Nott and James N. Grant 673

Letters to the Editor

EFFECT OF LAUNDERING ON SHIRTS. George H. Johnson. REPLY. Mary Anna Grimes and Carolyn A. Werman 680

BREAKING STRENGTH OF COTTON FIBER BUNDLES. C. Nanjundayya 682

IMPROVED METHOD FOR BULK COMPRESSION OF STAPLE FIBERS. S. M. Fok and T. G. Finzel. 684

Industrial Section

THE RELATION BETWEEN THE SOFTNESS OF HANDLE OF WOOL IN THE GREASY AND SCOURED STATES AND ITS PHYSICAL CHARACTERISTICS. N. F. Roberts 687

SPINDLE DRAFTING OF WOOLEN SLUBBINGS. J. Angus and J. G. Martindale 698

A STUDY OF THE USTER DYNAMOMETER AND THE SCOTT IP-2. D. S. Hamby and W. C. Stuckey 717

THE CHARACTERIZATION OF SPINNING QUALITY. J. F. Bogdan . 720

RANDOM TUMBLE PILLING TESTER. E. M. Baird, L. C. Legere, and H. E. Stanley 731

BOOK REVIEWS 736

Editor: Julian S. Jacobs *Production Editor:* Ellen Vogel

Associate Editors

H. J. Ball — W. J. Hamburger — Harold P. Lundgren
Earl E. Berkley — Milton Harris — H. Mark
Henry Eyring — K. L. Hertel — E. R. Schwarz

TEXTILE RESEARCH JOURNAL, published monthly at Prince and Lemon Streets, Lancaster, Pa., is devoted to the interest of research in textile and allied industries. It is published by Textile Research Institute.

Entered as second-class matter, April 27, 1945, at the post office at Lancaster, Pa., under the Act of August 24, 1912. Accepted for mailing at special rate of postage provided for in paragraph (d-2), Section 34.40, P. L. & R. of 1948, authorized May 9, 1950.

Manuscripts and communications should be sent to the Publications Department, P.O. Box 625, Princeton, N. J.

Subscription rates: $20.00 per year; additional for postage, 50 cents to Canada, $1.00 to all other countries. Single copies, $2.00 each.

Contents copyrighted © 1956 by Textile Research Institute. Advertising rates supplied on request.

Will

RHOPLEX

Acrylic Emulsions

Trigger the Next Big Idea

in Textiles?

NOW COMMERCIALLY AVAILABLE

A new and comprehensive series of Rohm & Haas acrylic emulsion polymers and copolymers is now available in commercial quantities.

Already, these low-cost emulsion polymers have made a name for themselves in . . . fabric finishes . . . pigment binders . . . non-woven fabric binders . . . fabric backings . . . warp sizes.

The films of these resins vary from extremely soft and flexible to hard and stiff. Like all acrylic resins, the films also display unusual clarity and resistance to light and aging. The polymers applied to fibers range from completely hydrophilic to strongly hydrophobic.

With Rohm & Haas acrylic emulsions, the next big development in textiles may be yours. Write today to Department R for complete information.

ACRYLIC MONOMERS ALSO AVAILABLE

Methyl acrylate	Methyl methacrylate
Ethyl acrylate	Ethyl methacrylate
Butyl acrylate	Butyl methacrylate
Glacial acrylic acid	Glacial methacrylic acid

2-Ethylhexyl acrylate

RHOPLEX *is a trade-mark, Reg. U.S. Pat. Off. and in principal foreign countries.*

Chemicals for Industry

ROHM & HAAS COMPANY

WASHINGTON SQUARE, PHILADELPHIA 5, PA.

Representatives in principal foreign countries

TEXTILE RESEARCH JOURNAL

VOL. XXVI, No. 9 SEPTEMBER 1956

The Relationship between the Structural Geometry of a Textile Fabric and Its Physical Properties[1]

Part VI: Nomographic Solution of the Geometric Relationships in Cloth Geometry[2]

Douglas P. Adams,[3] Edward R. Schwarz,[4] and Stanley Backer[5]

Massachusetts Institute of Technology, Cambridge, Mass.

Abstract

A simplified nomograph has been designed to permit rapid solution of Peirce's geometric relationships for plain weaves. To illustrate use of the nomograph, several practical problems in cloth structure are presented and worked out in some detail. Advantages and limitations of the nomograph are discussed.

Introduction

The beginning of fabric mechanics may be traced to F. T. Peirce's paper on the geometry of cloth structure, published in 1937 [3]. During the intervening years, many textile technologists have applied Peirce's basic analyses to a variety of mechanical problems. But the general utility of these geometric concepts has been limited by the form in which Peirce has presented his equations. For these require considerable calculation if the technologist is to use them in day-to-day quantitative predictions of cloth structure or behavior.

Several graphical solutions of the formal analyses have been reported as part of an extensive Quartermaster research program on cloth structure. The graphical form not only reduces computation time, but more important, gives a physical picture of the interaction between the geometric variables of cloth structure. Earlier published work by E. V. Painter [2] and L. Love [1] are examples of graphical tools useful to this special field of analysis.

The present work is an attempt to simplify and extend the accuracy of graphical solutions to the seven Peirce equations relating the eleven parameters of fabric geometry. It demonstrates the utility of a nomograph as contrasted to the conventional graphical solution. The nomograph of Figure 1 provides as many answers to problems in fabric geometry as one may obtain from Painter's graph but with considerable simplification of presentation.

It is clear that any closer plottings in the conventional graphical presentation would seriously

[1] This paper appears in the Quartermaster Textile Series, No. 93.

[2] Part I appeared in the November 1948 issue. Parts II, III, and IV appeared in the July, September, and October 1951 issues, respectively. Part V appeared in February 1956.

[3] Associate Professor of Engineering Graphics, Graphic Section, M.I.T.

[4] Professor of Textile Technology, in charge of Textile Section, M.I.T.

[5] Associate Professor of Mechanical Engineering, Textile Section, M.I.T., Quartermaster consultant.

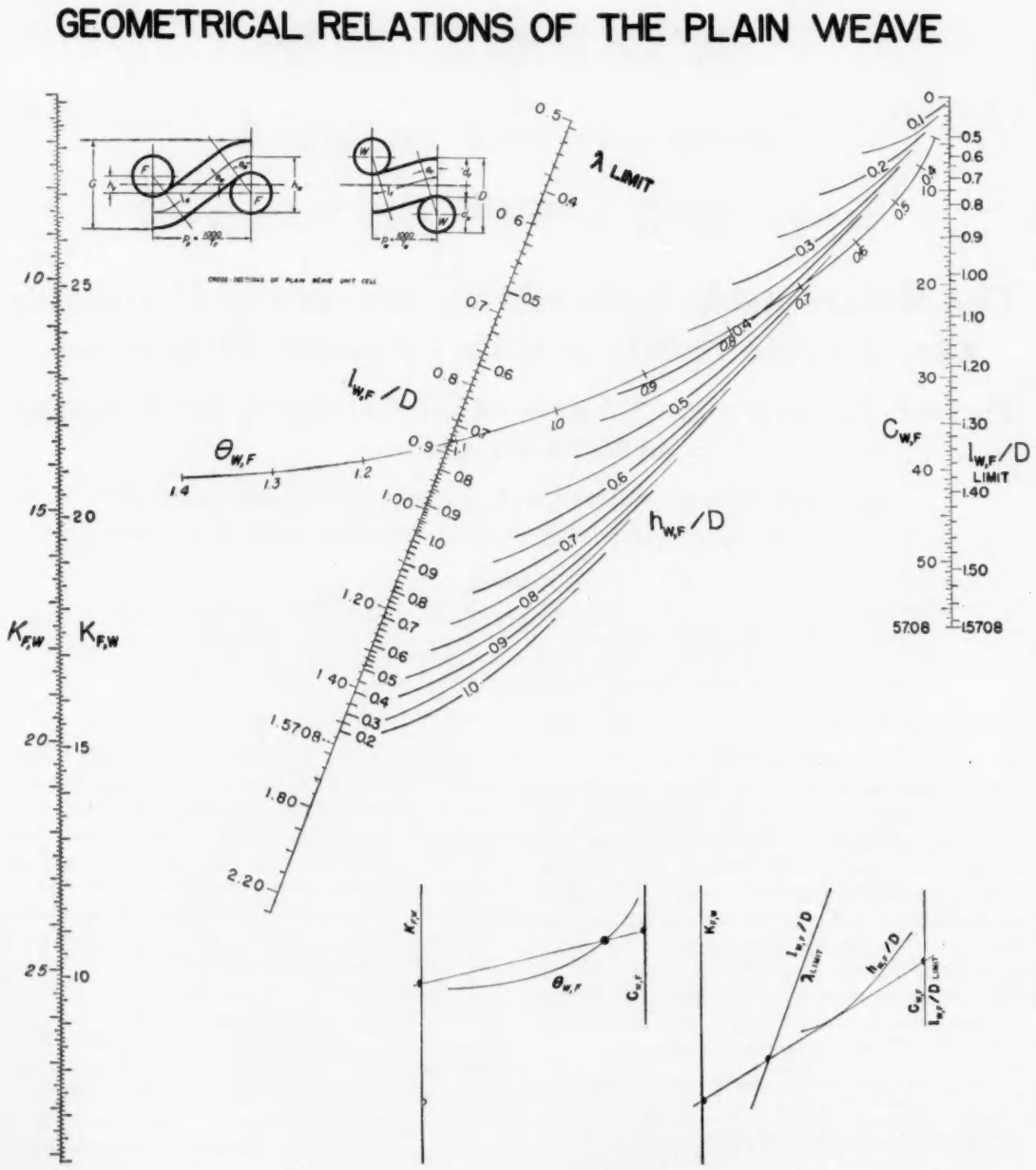


Fig. 1.* Nomagraph solution of plain weave geometry.

* Full size charts are available from the author on written request.

impair the readability of the graph. In the nomograph, the individual values of the geometric parameters are represented by points rather than lines. This dimensional reduction allows for a significant increase in direct reading accuracy.

A single scaled line now covers the range of variation in each of the common geometric parameters: cover factor $K_{f,w}$, angle of inclination $\theta_{w,f}$, relative yarn length $L_{w,f}/D$, and crimp $C_{w,f}$ (the subscripts w, f represent the warp and filling directions, respectively). The resulting elimination of numerous lines over the face of the graph allows for significantly closer readings for most of the parameters. For example, the minimum $L_{w,f}/D$ unit can be reduced by a factor reaching as high as 2.50 in some parts of the scale. The angle of inclination $\theta_{w,f}$ can easily be reduced by a factor of 15 or 20. Only in the case of the h/D (wave height) presentation are lines retained as lines—hence any reduction in minimum h/D scale units will impair readability.

Use of the Nomograph

The solution of each geometric problem takes the form of a straight line which intersects the parameter scales at the appropriate values of L/D, K, C, and θ. The parameter h/D is represented by a series of curved lines, and one must select as the appropriate value that particular h/D curve which is tangent to the straight line defining a solution.

The use of the nomograph can best be illustrated through examples. In applying Figure 1, one should note that the cover factor scales $K_{f,w}$ are based on the cotton yarn system. The relationship between yarn count N and yarn diameter d is taken to be

$$d_{1,2} = \frac{35.9}{\sqrt{N_{1,2}}} \quad (\text{in } 10^{-3} \text{ in.})$$

$$d_{1,2} = \frac{1}{27.9\sqrt{N_{1,2}}} \quad \text{in.} \qquad (1)$$

Equation 1 follows from Peirce's assumption that the specific volume of cotton yarn is 1.1. Note that subscripts 1, 2 or w, f will be used interchangeably in this report to represent warp and filling, respectively.

Peirce defined the cover factor $k_{1,2}$ as the ratio between the number of threads per inch of fabric $T_{1,2}$ and the square root of the yarn count, i.e.,

$$k_{1,2} = \frac{T_{1,2}}{\sqrt{N_{1,2}}} \qquad (2)$$

The average diameter $\bar{d}$ can be expressed in terms of (1) as

$$\bar{d} = \frac{D}{2} = \frac{d_1 + d_2}{2} = \frac{35.9}{2}\left(\frac{1}{\sqrt{N_1}} + \frac{1}{\sqrt{N_2}}\right) \qquad (3)$$

where D is the sum of the yarn diameters and the scale factor proposed by Peirce for cloth geometry. The reduced yarn number N which corresponds to $\bar{d}$ is defined as

$$\bar{d} = \frac{D}{2} = \frac{35.9}{\sqrt{N}} \qquad (4)$$

hence from (3) and (4),

$$\frac{2}{\sqrt{N}} = \frac{1}{\sqrt{N_1}} + \frac{1}{\sqrt{N_2}} \qquad (5)$$

as pointed out by Painter. If N is used in (2) in lieu of N_1 or N_2, the corresponding values of $k_{1,2}$ become the reduced cover factors $K_{1,2(r)}$, and according to Painter,

$$K_{1,2}\ (\text{reduced}) = 0.01395\, D\, T_{1,2} \qquad (6)$$

where D is expressed in mils, $T_{1,2}$ in threads per inch. The reduced cover factor $K_{f,w(r)}$ will be used in the graphical solution discussed in this report and will be designated simply as $K_{f,w}$.

Example 1

Problem: Given a cotton fabric with the following construction details:

	Warp	*Filling*
Yarn count (cotton)	13's	10's
Crimp	25.0%	7.6%
Threads/in.	55	45

a. Determine the cloth thickness, assuming no thread flattening. Determine L_1, L_2 and θ_1, θ_2.

b. How much fillingwise contraction will accompany a 5% cloth extension in the warp direction?

c. How much thickness change will occur if the warp is pulled until the filling jams?

d. How much warpwise and fillingwise shrinkage will take place if the fabric is immersed in water and the yarns are allowed to swell until jamming occurs?

Solution:

a. Calculate

$$d_1 = \frac{35.90}{\sqrt{N_1}} = 9.96 \text{ mils}$$

$$d_2 = \frac{35.90}{\sqrt{N_2}} = 11.35 \text{ mils}$$

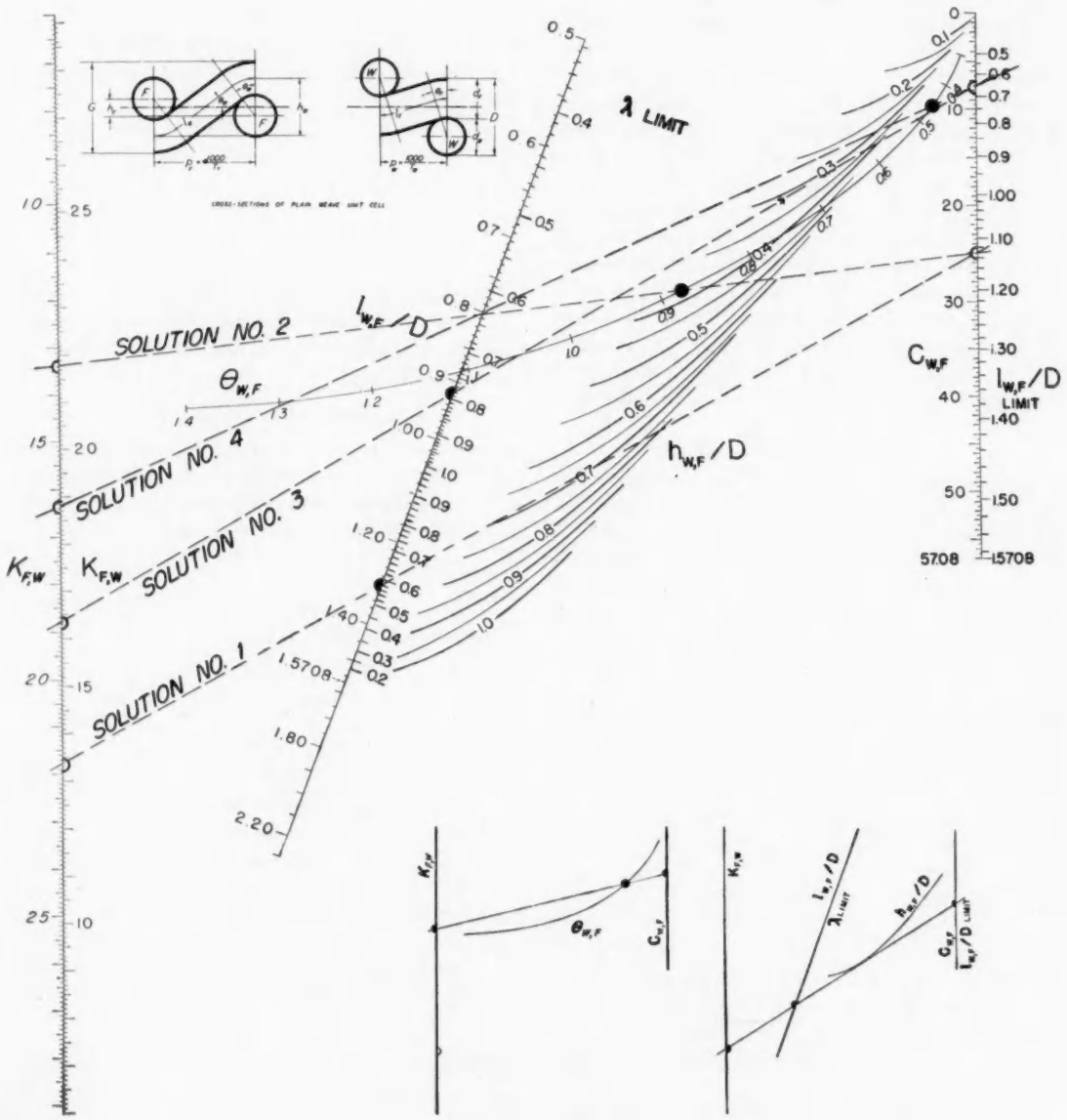


Fig. 2. Solution to Problem 1*a*.

$$D = d_1 + d_2 = 21.31 \text{ mils}$$
$$K_w = 0.01395\, DT_1 = 16.35$$
$$K_f = 0.01395\, DT_2 = 13.38$$

Enter nomograph on the right-hand $K_{f,w}$ scale, as per lower right-hand key instruction diagram of Figure 1. Connect the points $K_f = 13.38$ and $C_w = 25.0$ by a straight line, as in Figure 2 (Solution 1). Among the h/D lines, the $h_w/D = 0.7$ value comes closest to being tangent to this straight-line solution. Interpolation indicates that $h_w/D = 0.69$ would come even closer to sharing tangency with Solution 1 of Figure 2.

Solution 1 intersects the inclined L/D scale at $L_w/D = 1.30$, and it follows that

$$L_w = (1.30)(21.31) = 27.70 \text{ mils}$$

To determine θ_w, one again enters the nomograph with values of $K_f = 13.38$ and $C_w = 25.0$, this time using the left-hand K_f scale. The corresponding Solution 2 of Figure 2 intersects the θ curve at 0.88 radians.

It should be remembered that the subscript of K for a given calculation must differ from the subscript of all other parameters of Figure 1. It is for this reason that the scales are marked $L_{w,f}/D$: $h_{w,f}/D$:C_w, f but in the case of the cover factor, $K_{f,w}$. In other words, when determining h_w, C_w, L_w, and θ_w, use K_f, and conversely, when determining h_f, C_f, L_f, and θ_f, use K_w. Note also that the left-hand $K_{f,w}$ scale is used only in determination of $\theta_{w,f}$, respectively. In all other cases the right hand $K_{f,w}$ scale is used.

Figure 2 is entered at $K_w = 16.35$ and $C_2 = 7.6$. The connecting line is marked Solution 3 and is seen to intersect the L/D scale at 0.92 and lie tangent to $h_f/D = 0.31$. Thus L_f is 19.61 mils and h_f is 6.61 mils. Finally Solution line 4 intersects the θ_f scale at 0.45 and 1.29 radians. Noting that the warp yarn is more highly crimped than the filling, and that θ_w is 0.87 radians, one selects the value $\theta_f = 0.45$ radians.

To calculate the fabric thickness, one selects whichever is larger

$$h_1 + d_1 \quad \text{or} \quad h_2 + d_2$$

which are numerically

$$14.70 + 9.96 \quad \text{and} \quad 6.61 + 11.35$$

or 24.66 and 17.96, respectively. The fabric is therefore 24.7 mils thick, with warp crowns showing on face and back.

b. If one extends the fabric in question warpwise, c_1 will be reduced. We assume, however, that both L and D remain unchanged, i.e., that the mechanism of fabric extension is solely one of crimp interchange. The fractional warpwise extension can be expressed as

$$e_1 = \frac{p_{2n} - p_{2o}}{p_{2o}} = \frac{p_{2n}}{p_{2o}} - 1 \tag{7}$$

where n and o refer to new and original values of p_2, the filling yarn spacing. From the definition of fractional crimp, we note

$$p_2 = \frac{L_1}{(1 + c_1)} \tag{8}$$

and since L_{1n} and L_{1o} are equal

$$e_1 = \frac{(1 + c_{1o})}{(1 + c_{1n})} - 1 \tag{9}$$

When the original geometry of the cloth is known and an extension is specified for the warp direction, a more serviceable form of the above is

$$(1 + c_{1n}) = \frac{(1 + c_{1o})}{(1 + e_1)} \tag{10}$$

and for the case at hand

$$(1 + c_1) = \frac{1.25}{1.05} = 1.19$$

or the new C_1 is 19%.

Entering Figure 3 at $C_{1n} = 19$ and $L_1/D = 1.30$, the Solution 1 line is seen to intersect K_2 at 12.7 and to lie tangent to h/D (new) = 0.63. It follows from the original Peirce equation

$$\frac{h_1}{D} + \frac{h_2}{D} = 1 \tag{11}$$

that h_2/D new is 0.37. Now entering Figure 3 at $L_2/D = 0.92$ and $h_2/D = 0.37$, one notes Solution 2 intersects the K_w scale at 17.2 and the C_2 scale at 13.2.

From

$$e_2 = \frac{(1 + c_{2o})}{(1 + c_{2n})} - 1 \tag{12}$$

one calculates

$$e_2 = \frac{1.076}{1.132} - 1 = 0.95 - 1 = -0.05 = 5\% \text{ contraction}$$

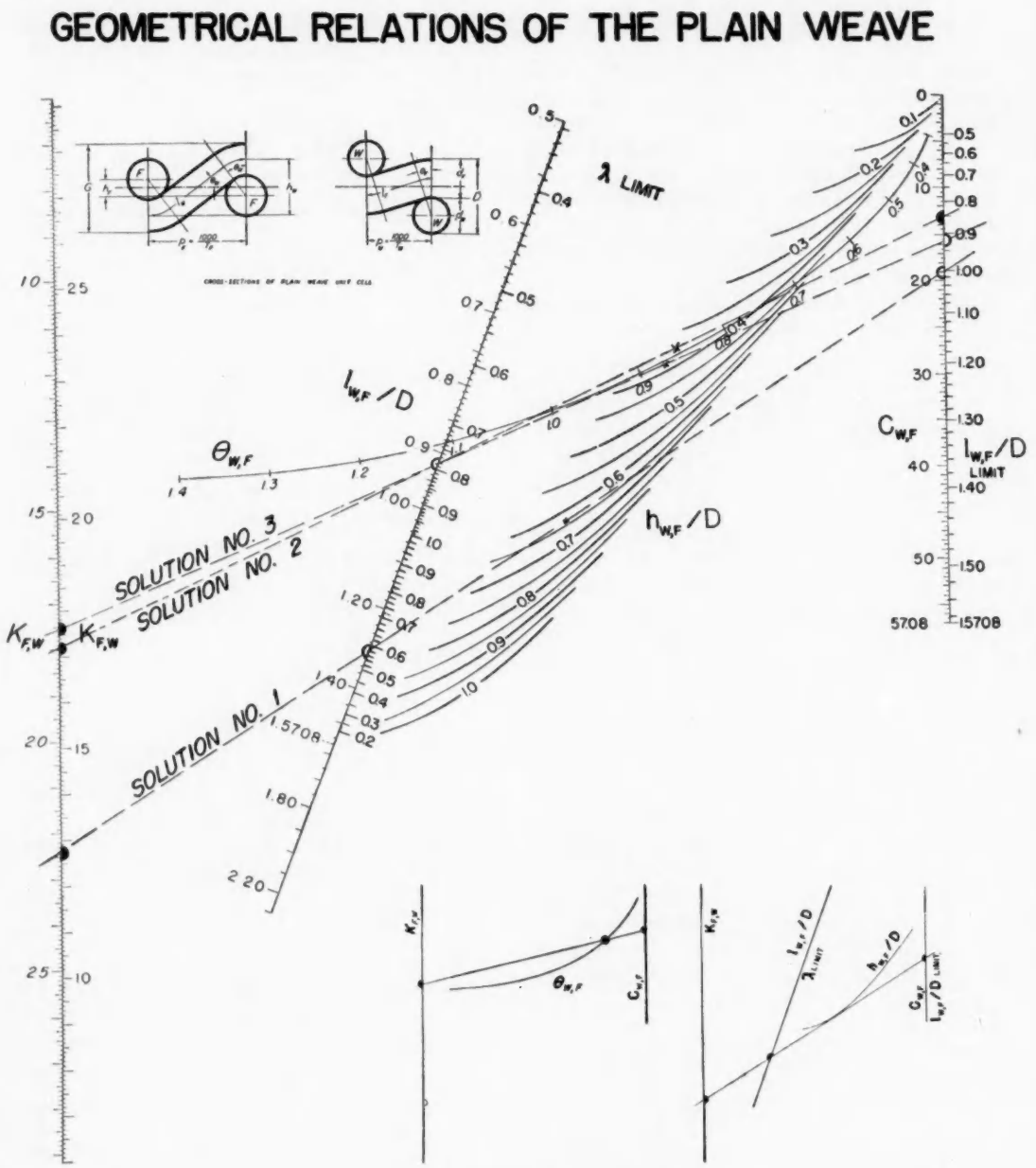


Fig. 3. Solution to Problems 1*b* and 1*c*.

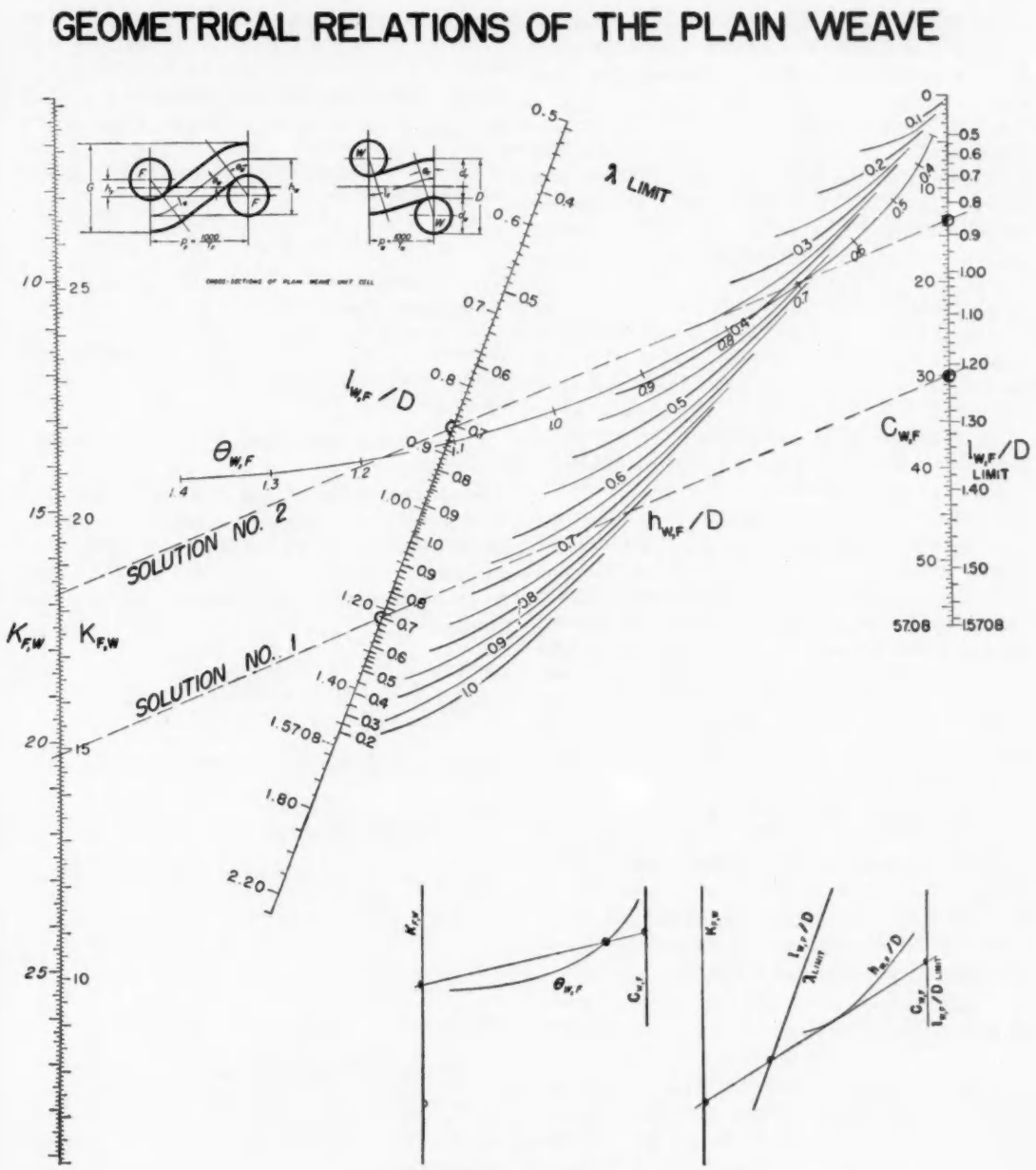


Fig. 4. Solution to Problem 1*d*.

Note that Solution 1 of Figure 3 represents a *counterclockwise* rotation of Solution 1 of Figure 2 about the $L_w/D = 1.30$ value. In similar manner, Solution 2 of Figure 3 represents a *clockwise* rotation of Solution 3 of Figure 2 about the value $L_f/D = 0.92$.

c. The jamming condition in the filling yarns is represented in the nomograph by the solution line joining equal values of the central L_f/D scale and of the right-hand L_f/D limit scale. Pulling the warp beyond a 5% extension will further increase the weft crimp and hence further rotate the filling Solution line 2 clockwise, as shown in Figure 3. Its limiting position (Solution 3) will be that which joins the center scale $L_2/D = 0.92$ and the right-hand scale L_2/D limit = 0.92, intersects K_1 at 17.6, and lies tangent to $h_2/D = 0.38$. It follows that $h_2 = 8.10$ mils. Now the $h_1/D = 0.62$ and $h_1 = 13.21$ mils. The new fabric thickness is 13.21 + 9.96, or 23.17 mils. The change in thickness from the original cloth geometry is 1.5 mils.

d. When free swelling takes place in a cloth structure, the following assumptions aid in defining the swollen structures. Assume d_1 and d_2 swell proportionately. Assume L_1 and L_2 remain constant, thus the ratio of L_1 to L_2, namely λ, remains constant and equivalent to the ratio of L_1/D to L_2/D. One enters the λ limit scale of the nomograph at two points corresponding to the L_1/L_2 ratio—or the L_2/L_1 ratio (whichever is less than 1.0). The swollen state values of L_w/D and L_f/D are read on the adjacent scale.

In the original cloth the λ ratio of L_w/D to L_f/D was 0.92/1.30 or 0.71. The corresponding L/D values in the swollen state are read at points adjacent to the two scale marks for $\lambda = 0.71$ and are 0.86 and 1.22, respectively, for filling and warp. Contrasted to the original L/D values of 0.92 and 1.30, respectively, the yarn swelling is

$$\text{Swelling} = \frac{D_n}{D_o} - 1 = \frac{L/D_o}{L/D_n} - 1 = \frac{1.30}{1.22} - 1 = 6.6\%$$

Since such swelling proceeds to the jam point for both warp and filling, the new solution lines are determined by joining the $L_1/D = 1.22$ values in the central and right-hand limit scales for the warp Solution 1, and the $L_2/D = 0.86$ values for the filling Solution 2, of Figure 4. One observes that in the swollen state $c_1 = 30\%$ and $c_2 = 13.5\%$. It follows that the fabric shrank

$$e_1 = \frac{1.25}{1.30} - 1 = 0.038$$

$$e_2 = \frac{1.076}{1.135} - 1 = 0.052$$

or 3.8% warpwise and 5.2% fillingwise.

Example 2

Problem: Given a : cotton fabric with the following construction details

	Warp	*Filling*
Yarn Count*	7.0	6.7
Crimp*	12.5	10.3
Threads/in.*	33.8	33.9

* Average of 5 tests.

Assume that whatever yarn flattening exists in the fabric is equally distributed between warp and filling yarns.

a. Determine the flattening factor of the yarn of this fabric.

b. Determine the change in filling dimensions of the cloth if the sample is extended 4.2% warpwise. Assume that during the warpwise pulling, the filling yarns are further flattened by 20% of their original flattened diameters, while the warp yarns do not change.

Example 2

Solution:

$$a.\ d_1\ (\text{round}) = \frac{35.90}{\sqrt{7}} = 13.57 \text{ mils}$$

$$d_2\ (\text{round}) = \frac{35.90}{\sqrt{6.7}} = 13.87 \text{ mils}$$

$$D\ (\text{round}) = 13.57 + 13.87 = 27.4 \text{ mils}$$

$$p_1 = \frac{1000}{33.8} = 29.6 \text{ mils}$$

$$p_2 = \frac{1000}{33.9} = 29.5 \text{ mils}$$

From Peirce's approximate formula,

$$h_1 = \tfrac{4}{3} p_2 \sqrt{c_1} = \tfrac{4}{3}(29.5)(0.354) = 13.9 \text{ mils}$$

$$h_2 = \tfrac{4}{3} p_1 \sqrt{c_2} = \tfrac{4}{3}(29.6)(0.321) = 12.7 \text{ mils}$$

$$h_1 + h_2 = D \text{ (flattened)} = 26.6 \text{ mils}$$

From Equation 6, one now calculates approximate reduced cover factors based on the first calculation of D (flattened), that is 26.6 mils. For K_1 one obtains 12.54 and for K_2 12.58. Entering the nomograph at K_1 12.54 and C_2 10.3% one reads

h_2/D 0.49. Similarly for K_2 12.58 and C_1 12.5%, h_1/D is read as 0.53. Dividing each of these quantities by their sum, 1.02, one obtains the corrected h_2/D 0.48 and h_1/D 0.52.

Entering the nomograph of Figure 5 at points $h_1/D = 0.52$ and $C_1 = 12.5$, one locates Solution line 1, which intersects the K_2 scale at 12.75 and the L_1/D scale at 1.23. One now calculates an improved estimate of the flattened D

$$D = \frac{K_2}{0.01395\ T_2} = \frac{12.75}{(01395)(33.9)} = 26.96 \text{ mils}$$

The quantity 27.0 serves as a second estimate of the flattened diameter sum D and will be adopted as the more reliable value. The flattening factor f is defined as

$$f = \frac{D \text{ (flat)}}{D \text{ (round)}}$$

and in this case

$$f = \frac{27.0}{27.4} = 0.985$$

b. When the fabric is extended 4.2% in the warpwise direction,

$$(1 + c_1) = \frac{1 + c_{1o}}{1 + e_1} = \frac{1.125}{1.042} = 1.079$$

$$C_{1n} = 7.9\%$$

$$d_{1o} \text{ (flat)} = (0.985)(13.57) = 13.37 \text{ mils}$$

$$d_{2o} \text{ (flat)} = (0.985)(13.87) = 13.62 \text{ mils}$$

Assuming 20% additional flattening in the filling,

$$d_{2n} \text{ (flat)} = (0.80)(13.6) = 10.9$$

$$D_n = 13.4 + 10.9 = 24.3 \text{ mils}$$

On the assumption that L_1 remains constant,

$$\frac{D_o}{D_n} = \frac{L_{1n}/D_n}{L_{1o}/D_o}$$

and

$$\frac{L_{1n}}{D_n} = \frac{27.0}{24.3}(1.23) = 1.36$$

Entering the nomograph of Figure 5 at $L_1/D = 1.36$ and $C_1 = 7.9$, one observes from Solution 3 that h_{1n}/D is 0.48 and K_2 is 11.1. It follows that h_{2n}/D is 0.52. From the original data and Solution 2, L_{2o}/D is 1.21 and as a result of flattening, L_{2n}/D becomes 1.34. Solution 4 for the latter conditions, $h_{2n}/D = 0.52$ and $L_{2n}/D = 1.34$, intersects the C scale at C_{2n} equals 10.2%. Thus the filling will remain about the same, or even extend slightly.

$$e_2 = \frac{1.103}{1.102} - 1 = 0.0009$$

or

e_2 is 0.1% extension

Example 3

Problem: Given: a cotton fabric which is completely balanced in warp and filling directions. The fabric is wet out and allowed to swell until jamming occurs. The cloth is then reduced in thickness 19.5% from the swollen state. What change in length and width may be expected?

Solution a. Assume that a flat bed press is used to reduce fabric thickness, allowing equal change in warp and filling directions. Assume also that the yarn length remains constant.

Enter the nomograph of Figure 6 on the λ scale at $\lambda = 1.0$, which follows from the statement of complete cloth balance. The corresponding L_1/D and L_2/D values at jam are both 1.047. As D changes 19.5%,

$$\frac{L_{1n}}{D} = \frac{L_{2n}}{D} = \frac{1.047}{0.805} = 1.30$$

The Solution 2 line is determined by $L_{1,2}/D = 1.30$ and $h_{1,2}/D = 0.50$ (from the condition of balance) giving $C_{1,2n} = 9.5\%$. Solution line 1 representing the original fabric joins $L/D = 1.047$ points on the central and right-hand scales, giving $C_{1,2,o} = 21.0\%$. The warpwise and fillingwise extension is now

$$e = \frac{1 + c_{1,2o}}{1 + c_{1,2n}} - 1 = 0.106$$

or 10.6%.

Solution b. A more common means of reducing fabric thickness is through calendering. Here one may assume (as in the cold rolling of steel plate) that no dimensional change is effected across the width of the rolled material. The longitudinal direction on the other hand takes all the strain, corresponding to the warpwise direction. One also assumes equal flattening in warp and filling.

Enter the nomograph as before to determine the original crimp and L/D of the fabric to be 21% and 1.047, respectively (Solution 1 of Figure 6). From the above assumption it follows that

$$C_2 \text{ old} = C_2 \text{ new}$$

$$L_1 \text{ old} = L_1 \text{ new}$$

$$L_2 \text{ old} = L_2 \text{ new}$$

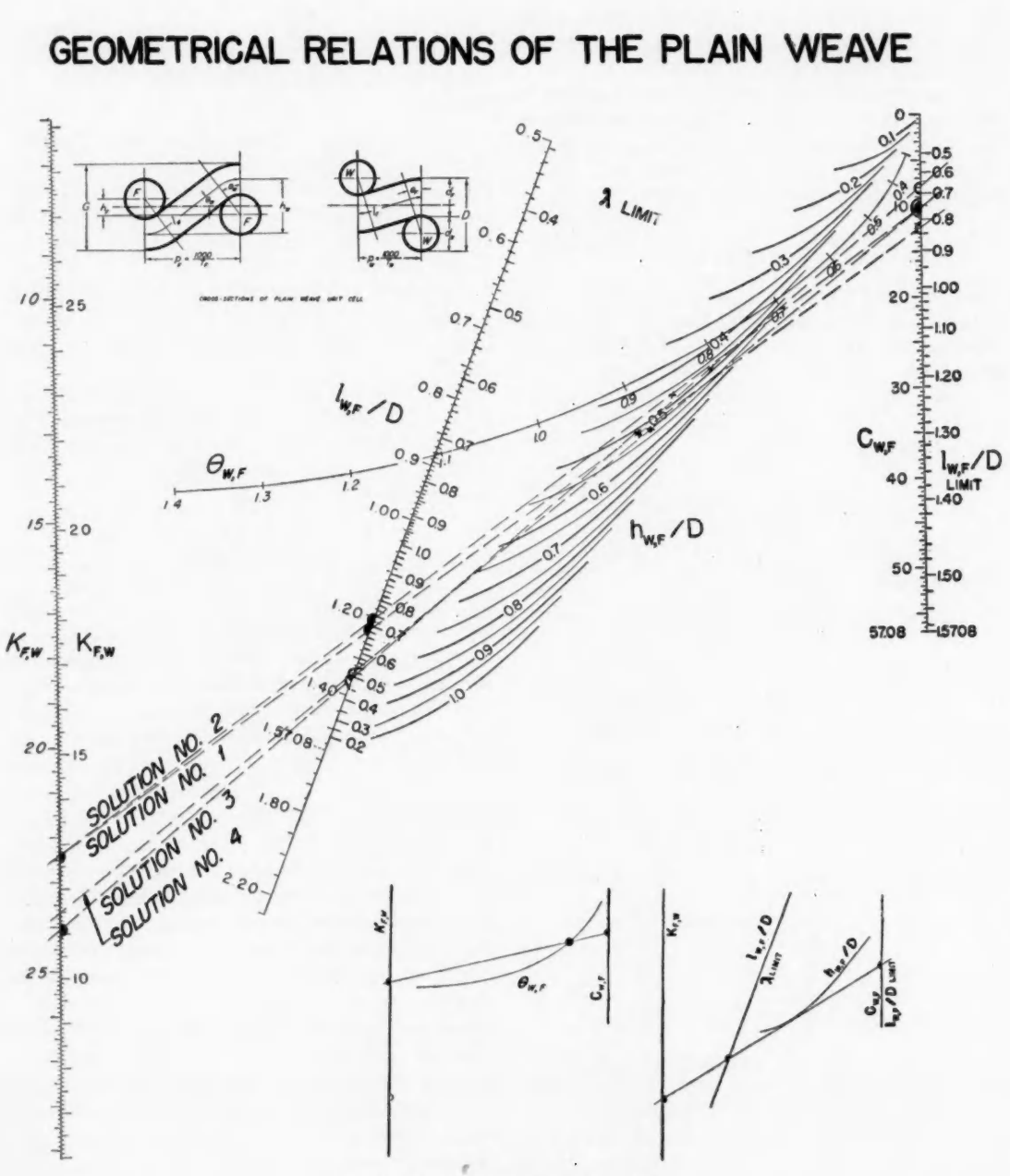


Fig. 5. Solution to Problems 2*a* and 2*b*.

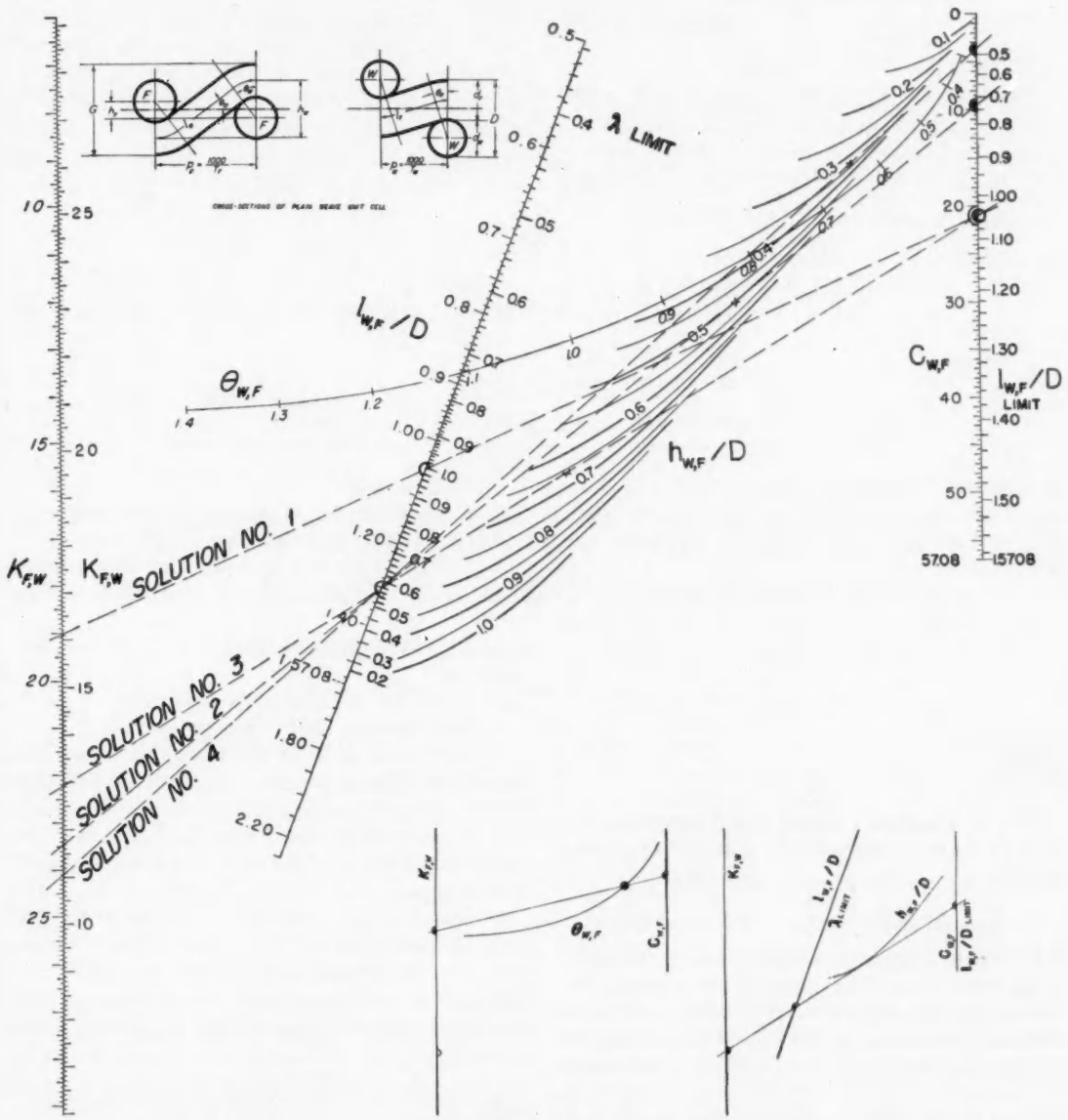


Fig. 6. Solution to Problem 3.

TABLE I. Numerical Solutions from Figures 2 to 6

	K_f	L_w/D	h_w/D	C_w	θ_w	K_w	L_f/D	h_f/D	C_f	θ_f
Figure 2										
Solution 1	13.38	1.30	0.69	25.0						
2	13.38			25.0	0.88					
3						16.35	0.92	0.31	7.6	
4						16.35			7.6	0.45
Figure 3										
Solution 1	12.7	1.30	0.63	19.0						
2						17.2	0.92	0.37	13.2	
3						17.6	0.92	0.38		
Figure 4										
Solution 1		1.22		30.0						
2							0.86		13.5	
Figure 5										
Solution 1	12.75	1.23	0.52	12.5						
2						12.75	1.21	0.48	10.3	
3	11.1	1.36	0.48	7.9						
4							1.34	0.52	10.2	
Figure 6										
Solution 1		1.047		21.0						
2		1.30	0.50	9.5						
3							1.30	0.66	21.0	
4		1.30	0.34	3.7						

As indicated in Solution *a* above, both L_{1n}/D and L_{2n}/D are equal to 1.30, hence Solution line 3 joins $L_2/D = 1.30$ and $C_2 = 21\%$ touching $h_2 = 0.66$. Now h_1/D is 0.34. Entering Figure 6 at $L_1/D = 1.30$ and $h_1/D = 0.34$, one notes from Solution line 4 the $C_1 = 3.7\%$. Considering the warp direction note that

$$e_1 = \frac{1 + c_{1o}}{1 + c_{1n}} - 1 = \frac{1.210}{1.037} - 1 = 0.168$$

or that

$$e_1 = 16.8\%$$

Finally, a summary listing of the numerical solutions to the three problems cited above is furnished in Table I.

General Application of the Nomograph

In all, the range of problems which can be solved easily with the aid of Figure 1 is indeed great. Rather than provide the detailed solution to one or two more problems, it might be well to list a number of typical calculations which will be of interest to the reader.

If one is given the yarn counts, threads per inch, and yarn crimps, the following determinations are facilitated by use of the nomograph of Figure 1.

a. The complete geometric specification of the woven cloth.

b. Cloth weight.

c. Extensibility in orthogonal uniaxial tension.

d. Cloth thickness.

e. Relative tightness in warp and filling directions (using Love's [1] graphs in addition to Figure 1).

f. Shrinkage in both directions due to yarn swelling.

g. Thickness of cloth in a wetted state.

h. Reed spacing used to weave fabric.

i. Reed spacing to be recommended to achieve maximum filling crimp for the given finished textures.

j. Reed spacing and loom picks per inch to achieve a fabric structure of maximum abrasion resistance.

k. Assuming the given fabric is used as a filter cloth, determination of the weight of fabric of equivalent texture (threads per inch in warp and filling) designed to pass particles twice the size of the particles which will pass through the original filter material.

The utility of the nomograph is of course subject to the limitations of the basic Peirce equations. Obviously the solution presented in the above illustrations will be open to question when L_1 or L_2 cannot be considered constant, where the yarn is excessively flattened, where yarn rigidity is signifi-

cant, where lateral dislocation of the yarn occurs (due to unsymmetric pressures, say in a twill weave), where the unit cell is sheared, or where yarn packing densities are altered. In all such cases it remains for the technologist to observe carefully the strength of Peirce's assumptions. Where the fabric in question fails in regard to any one assumption, the general utility of the geometric analysis is restricted. But whatever the restriction on such analysis, the technologist who is familiar with the geometric treatment is in a stronger position to anticipate fabric behavior than is the textile empiricist.

Acknowledgment

The support of this work by the Textile Clothing and Footwear Division of the Quartermaster Research and Development Command, Natick, Mass., is acknowledged. Thanks are due Dr. S. J. Kennedy and L. I. Weiner for their encouragement in this study. The careful work of Raymond Smith in the preparation of the original nomograph drawing is acknowledged.

Literature Cited

1. Love, L., "Graphical Relationships in Cloth Geometry for Plain, Twill, and Sateen Weaves," TEXTILE RESEARCH JOURNAL **24**, 1073 (1954).
2. Painter, E. V., "Mechanics of Elastic Performance of Textile Materials; VIII, Graphical Analysis of Fabric Geometry," TEXTILE RESEARCH JOURNAL **22**, 153 (1952); **22**, 556 (1952).
3. Peirce, F. T., "The Geometry of Cloth Structure," *J. Textile Inst.* **28**, T45 (1937).

Manuscript received January 2, 1956.

A Fiber Length Tester with Automatic Punched-Card Registration

J. H. Wakelin, H. W. Lambert, and D. J. Montgomery[1]

Textile Research Institute, Princeton, N. J.

Introduction

Studies on wool and cotton conducted at Textile Research Institute [8, 10, 12] and elsewhere have shown that the mean fiber length and the fiber length distribution influence the processing characteristics of these fibers through the carding, combing, drawing, and spinning operations. The apparatus described here has been developed to provide a rapid method for recording single fiber length data on punched cards so that the arithmetic steps in determining the mean fiber length, variance, standard deviation, and other properties of the length distribution may be performed automatically on standard punched-card calculating equipment [11]. The automatic recording of single fiber lengths, the principal feature and advantage of this apparatus, makes it possible to obtain quickly and precisely information on fiber length distribution for correlation with the performance of fibers through the mechanical stages of industrial processing.

[1] Present address: Michigan State University, East Lansing, Mich.

The Fiber Length Tester

General Description

The Fiber Length Tester designed for the automatic registration of single fiber data is a modification of the Automatic Fibre Length Measuring Machine developed by the Wool Industries Research Association [1]. The essentials of the tester include (1) a spring clamp for holding one end of a single fiber, (2) a screw-driven carriage, to which the spring clamp may be attached, for drawing the fiber across a felt pad, (3) a mercury cup switch to stop the carriage when the free end of the fiber passes clear of an arm near the felt pad, (4) two decimal

counter switches for recording fiber length, or carriage traverse, in inches and tenths of inches, and (5) a relay and plugboard wiring system for transmitting these two digits for automatic registration on cards by the IBM Reproducing Punch [6]. Figure 1 is a photograph of the assembled equipment. The principal components of the length tester are sketched in Figure 2, and the circuit diagram is shown in Figure 3.

The fibers to be measured are placed on the platform at the left of the apparatus. In Figure 1, a sample of top may be seen, prepared for testing by the "cut-square" technique [4, 9], with its end lightly clamped under a polystyrene strip. Each fiber to be tested is gripped by the spring clamp about 0.1 in. from the end and then led across the felt pad toward the right where the clamp is placed into a support on the carriage. The end of the clamp is pushed against the felt pad base which forms the fiducial point for the zero length setting of the carriage. The carriage motion to the right is then started by actuating the motor drive for the screw to which the carriage is attached. For each tenth-inch traverse of the carriage a cam on the right end of the screw shaft delivers an impulse to one of two decimal stepping switches; the length in inches is registered on the other stepping switch by the advance of one digit for every ten on the first stepping switch. The

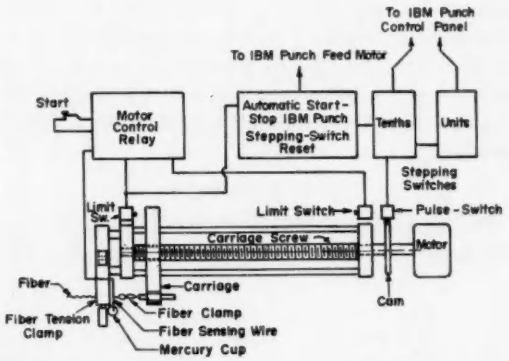


Fig. 2. Sketch of the principal components of the Fiber Length Tester.

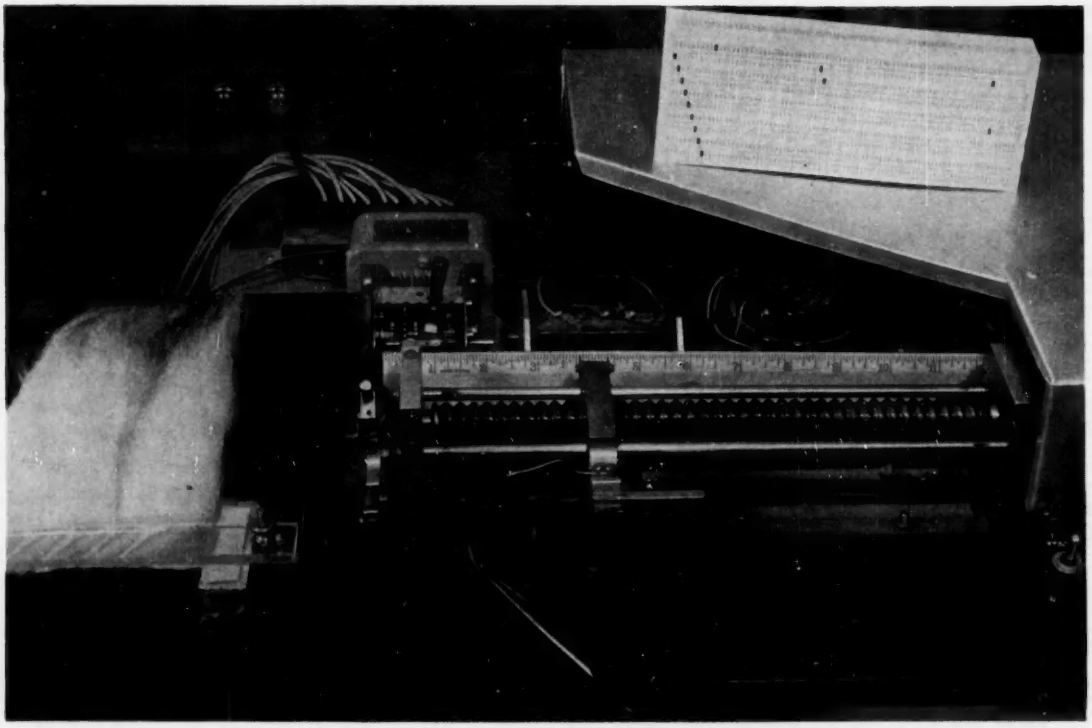


Fig. 1. The Fiber Length Tester.

carriage motion is stopped and reversed by the action of a fiber-sensing mercury cup switch. After the carriage returns to its starting position, the two-digit representation of fiber length is transmitted through a twelve-wire circuit from the counters to the punching brushes of the Reproducing Punch. This circuit also starts the Reproducing Punch for one card cycle during which the punched card is advanced toward the receiving hopper, and a new card to be punched is advanced to the punching station.

Registration of Data

The Fiber Length Tester and Reproducing Punch are wired together so that the system automatically goes through one complete cycle of length measurement and card punching from the time the carriage is started until it returns to its starting position for the next measurement. A sample card for this system is displayed on the metal cover of the Fiber Length Tester at the right in Figure 1. The first nine columns at the left of the card are prepunched one through nine successively; the tenth column is prepunched with a zero. The length data for a given fiber may then be punched in any two of the remaining seventy columns. In the card in Figure 1, length data for two fibers are punched near the middle (columns 34 and 35) and near the right-hand edge (columns 73 and 74) of the card. In the present method the length of a single fiber is punched on one card, that for the next on the succeeding card, and so forth, so that there are as many cards punched as fibers tested. By a simple change of the wiring on the plugboard of the Reproducing Punch, the length data for another set of fibers can be punched in different columns of the same deck of cards so that 100 cards provide storage for length measurements made on 3500 fibers.

When the length data are complete on a group of fibers, the deck of punched cards is transferred to the Calculating Punch. Statistical information such as mean length, variance, and standard deviation are automatically computed and the results punched in a single summary card. In certain cases to be re-

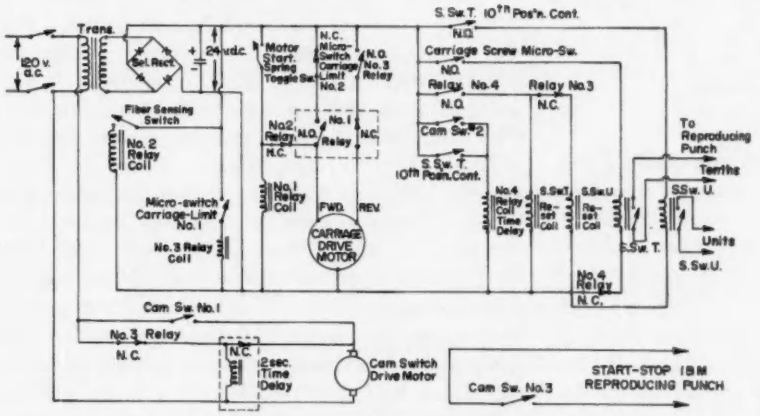


Fig. 3. Diagram of the control circuit of the Fiber Length Tester.

The Control Circuit. The carriage is started by closing motor-start switch to energize #1 relay coil, which actuates the motor to forward drive through the self-holding #1 relay contact. As the carriage moves away from #1 limit switch, #3 relay coil is energized, closing #3 relay contact and transferring the control of the carriage motor to the fiber-sensing switch and then to #2 relay coil. For every tenth inch of traverse of the carriage, or one half of each shaft rotation, the carriage-screw microswitch is closed, providing an impulse to stepping switch T, advancing it one position. When stepping switch T moves to the tenth position, stepping switch U is advanced one position, and T is reset by #4 relay coil. While this stepping switch is being reset, the contacts on #3 relay are opened to prevent the resetting of stepping switch U.

As the fiber end is pulled beneath the fiber-sensing switch, #2 relay is energized, releasing #1 relay and reversing the carriage motor. On return to its starting position the carriage actuates limit switch #1, opening #3 relay coil, stopping the carriage, and starting the cam-drive motor. Shortly after the cam-drive motor starts, cam switch #1 closes and controls the motor, the two-second time delay switch opening the line from #3 relay. During the cycle in which the cam-drive motor is in operation, the Reproducing Punch is started by cam switch #3, and the fiber length data are automatically transferred from the stepping switches to the Reproducing Punch and punched into a card. Cam switch #2 is then closed, resetting the two stepping switches; cam switch #1 is opened, stopping the cam-drive motor. The system is now ready for the next fiber length measurement.

ported later, the third moment, or skewness, of the fiber distribution has been calculated in order to determine the extent to which the measured length distribution departs from a normal distribution, and to determine whether the "tail" of the distribution lies above or below the mean length.

Calibration and Accuracy

The Fiber Length Tester was calibrated by comparing the mean lengths of a fiber group measured first on the Fiber Length Tester and then manually against a rule with a least count of 0.05 in. To represent wool, a sample of 80 fibers was selected from roving made from a lot of the Corriedale type of 56's quality grade; for cotton a sample of 300 fibers was selected from card sliver made from a lot of the Deltapine 15 variety, 1951 crop. For each fiber type the mean lengths of the group did not differ significantly. The paired differences were found to be normally distributed about a mean value which, however, did differ significantly from zero, indicating a bias less than the least count, or 0.10 in., of the Fiber Length Tester. A summary of the length data for the wool and cotton fiber groups used in this comparison is given in Table I.

Experimental Results

Wool

Fiber length distributions have been obtained with the Fiber Length Tester for top samples representing the four wool types processed on the Wool Research Project [12]. Length data have also been obtained for wool tops made from Columbia, Targhee, and Rambouillet of the 1950, 1951, and 1952 clips, provided from the same flocks by the U.S. Sheep Experiment Station of the U.S.D.A. in Dubois, Idaho, and made available on loan to the Institute by the University of Idaho [8]. In addition, fiber lengths were measured on grease wool samples and card sliver for the 1952 clip of these three wool types in order to study fiber breakage in the early stages of mechanical processing.

Sample selection, sample preparation, and the unbiased choice of fibers for measurement are critical factors in fiber length measurement. For materials such as grease wool, no completely satisfactory method exists. The procedure used in the present work has been to select randomly 100 staples of each wool type and withdraw at random two fibers from each staple. The "cut-square" method of Daniels [4] as modified by Palmer [9] was used in testing card sliver and top. This technique was devised for parallel fiber assemblies such as top, roving, and yarn; however, it was utilized for card sliver in the present work, instead of the dye-sampling technique proposed by Palmer [9], because the fibers in the sliver were fairly well parallelized. No study has been made to evaluate the effect of the orientation of the fibers in the sliver on the fiber length data obtained by the dye-sampling and "cut-square" methods. However, the Forstmann Woolen Company has very kindly permitted the use of their data on the same wool types and clips for comparison with the results of the Fiber Length Tester. For the grease wool staples, Forstmann used the stretched staple length, or U.S.D.A. method [7], and for card sliver and top, the A.S.T.M. method [2]. The latter method, with the comb sorter, provides a weight average mean length, whereas the Fiber Length Tester provides a number average mean length. For comparison of these two methods the measurements on the Fiber Length Tester have been length-biased to provide a new distribution in which the percentage of fibers in each length group is proportional to the product of the average length of the group and the percentage of fibers actually found in that group by length measurement. If there is no strong correlation between fiber diameter and fiber length, then good agreement should be found, as it

TABLE I. Calibration of Fiber Length Tester with Wool and Cotton Fibers

	Fiber Length Tester		Manual measurement		Paired Differences (M. M.−F.L.T.)	
Sample	Mean length (in.)	Std. dev. (in.)	Mean length (in.)	Std. dev. (in.)	Mean length (in.)	Std. dev. (in.)
Wool	3.446	(1.46)	3.467	(1.48)	0.021	(0.066)
Cotton	0.871	(0.324)	0.921	(0.330)	0.050	(0.094)

was, between the length-biased and comb-sorter data.

The length data provided by the Fiber Length Tester and the A.S.T.M. comb-sorter method are presented in Table II for tops made from the four wool types studied on the Wool Research Project during the period 1948–1952. Comparison of the length-biased single fiber and the weight-average A.S.T.M. results indicates good agreement.

Length data comparing the A.S.T.M. and the fiber length methods have also been obtained for wool tops made from Rambouillet (R64), Targhee (T60) and Columbia (C56) wools representing the 1950(0), 1951(1) and 1952(2) clips. The results of these measurements are shown in Table III.

A further study of fiber length was made to compare the results, using the U.S.D.A. method [7] for grease wool and the A.S.T.M. comb-sorter method [2] for sliver and top with those obtained with the Fiber Length Tester. Two hundred fibers were withdrawn from grease wool staples, card sliver, and top samples representing the Rambouillet, Targhee, and Columbia wool types of the 1952 clip. The results are summarized in Table IV and illustrated in Figure 4. The data on fiber distribution for grease wool, card sliver, and top of the 1952 clip of Targhee wool are shown in Figure 5.

It is seen that the agreement between the A.S.T.M. and Fiber Length Tester methods is better for top than for card sliver and may possibly be attributed to fiber breakage during sample preparation in the former method. The lengths of grease wool staples by the U.S.D.A. method appear to be considerably shorter than the actual number average length of the fibers in the staple; however, the usefulness of the U.S.D.A. method lies in its high correlation with average fiber length in finished tops.

The progression of the fiber length distribution may be seen in Figure 5, showing that the tail of

TABLE II. Comparison of Fiber Length Data of Four Wool Tops Obtained by the A.S.T.M. Method and the Fiber Length Tester

	Fiber Length Tester*				A.S.T.M.		
Wool types	Mean length (Number av.) (in.)	Std. dev. (in.)	Skewness	Mean length (Length-biased) (in.)	Mean length (Weight av.) (in.)	Std. dev. (in.)	F.L.T.–A.S.T.M. (in.)
Australian fine	1.97	(0.77)	+0.44	2.32	2.41	(0.90)	−0.09
U. S. fine	2.33	(1.21)	+0.21	2.80	2.83	(0.98)	−0.03
U. S. medium	2.36	(1.55)	+0.74	2.94	3.19	(1.20)	−0.25
New Zealand medium	2.43	(1.74)	+0.75	3.11	3.22	(1.22)	−0.11

* 400 fibers measured for each mean length tabulated.

TABLE III. Comparison of Fiber Length Measurements on Idaho Wool Tops Using the A.S.T.M. Method and the Fiber Length Tester

	Fiber Length Tester*			A.S.T.M.		
Wool types and clips	Mean length (Number av.) (in.)	Std. dev. (in.)	Mean length (Length-biased) (in.)	Mean length (Weight av.) (in.)	Std. dev. (in.)	F.L.T.–A.S.T.M. (in.)
R640	2.55	1.11	3.03	2.64	0.94	+0.39
R641	2.64	1.17	3.14	2.90	0.96	+0.24
R642	2.56	1.19	3.18	2.90	1.05	+0.28
T600	2.55	1.09	3.01	3.10	1.14	−0.09
T601	2.90	1.23	3.42	3.00	1.08	+0.42
T602	2.80	1.26	3.43	3.33	1.14	+0.10
C560	2.83	1.22	3.34	3.32	1.16	+0.02
C561	2.89	1.35	3.52	3.52	1.25	0.00
C562	2.60	1.35	3.41	3.64	1.31	−0.23

* 200 fibers tested for each mean value listed.

distribution lies below the mean value for grease wool, giving rise to a negative value for skewness, while the tail of the distribution for card sliver and top lies above the mean value, giving rise to a positive value for skewness.

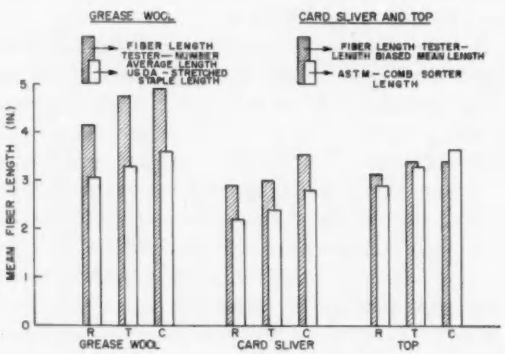


Fig. 4. Comparison of mean fiber lengths by U.S.D.A. method for grease wool and A.S.T.M. method for sliver and top with measurements obtained with the Fiber Length Tester. Legend R = Rambouillet, T = Targhee, and C = Columbia.

Cotton

Fiber length data on cottons have been used to study the influence of temperature during the gin-

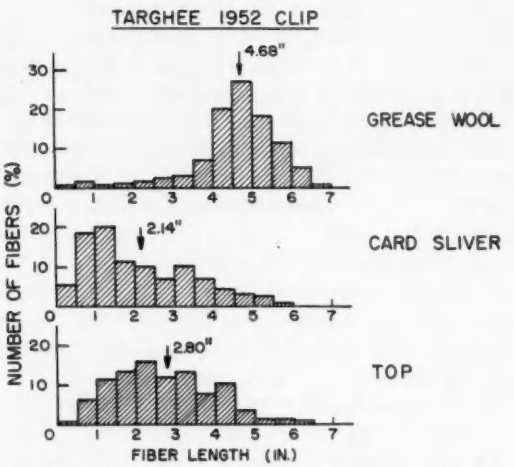


Fig. 5. Fiber length distributions for grease wool, card sliver, and top of the 1952 clip of Targhee wool.

TABLE IV. Comparison of Fiber Lengths by U.S.D.A. Method for Grease Wool and A.S.T.M. Method for Silver and Top, with Measurements Obtained with the Fiber Length Tester

(a) Grease Wool

	Fiber Length Tester			U.S.D.A.		
Wool type	Mean length (Number av.) (in.)	Std. dev. (in.)	Skewness	Mean length (Number av.) (in.)	Std. dev. (in.)	F.L.T.–U.S.D.A. (in.)
R642	4.16	1.18	−1.47	3.04	0.40	+1.12
T602	4.68	1.08	−1.36	3.28	0.40	+1.40
C562	4.78	1.69	−1.60	3.62	0.27	+1.16

(b) Card Sliver and Top

	Fiber Length Tester				A.S.T.M.		
Wool type	Mean length (Number av.) (in.)	Std. dev. (in.)	Skewness	Mean length (Length-biased) (in.)	Mean length (Weight av.) (in.)	Std. dev. (in.)	F.L.T.–A.S.T.M. (in.)
				Card Sliver			
R642	2.27	1.28	−0.17	2.92	2.21	1.10	+0.71
T602	2.14	1.46	+0.74	3.00	2.38	1.21	+0.62
C562	2.36	1.56	+0.69	3.56	2.79	1.30	+0.77
				Top			
R642	2.56	1.19	+0.86	3.18	2.90	1.05	+0.28
T602	2.80	1.26	+0.29	3.43	3.33	1.14	+0.10
C562	2.60	1.35	+0.54	3.41	3.64	1.31	−0.23

ning operation and of microbiological attack during storage [10]. Histograms representing length measurements made on Rainmed [2] and Cavitomic Rainmed cottons are shown in Figure 6, wherein a comparison indicates the higher number of fibers in the shorter length groups for the Cavitomic or microbiologically-attacked cotton. The mean fiber lengths of these two cottons do not reflect as clearly as the fiber length distribution the effect of microbiological attack; these data are reported in Table V, together with mean lengths measured on the Suter Webb Sorter [3] and the Uster Staple Apparatus [5]. The Suter Webb Sorter provides a weight average length, and these mean values have been transformed to number average lengths for direct comparison with measurements made on the Uster Staple Apparatus and the Fiber Length Tester. The Uster Staple Apparatus and the Fiber Length Tester give significant differences between the mean length values for Rainmed and Cavitomic Rainmed cottons, while the Suter Webb Sorter does not distinguish between them.

Conclusions

A Fiber Length Tester has been developed, the principal advantage of which is the automatic registration of data on punched cards. This tester has been found satisfactory for measuring wool fibers withdrawn from raw wool staples, card sliver, top, roving, and yarn; and for measuring cotton fibers withdrawn at similar stages in processing. The number average mean values of length with this tester are generally considerably higher than those determined from grease wool staples by the U.S.D.A. method, and considerably lower than those obtained with the A.S.T.M. method for card sliver and top. However, acceptable agreement for top is obtained when length-biased mean lengths are compared with the A.S.T.M. comb-sorter results. The Fiber Length Tester, in measuring a number average mean length of extended fibers, may provide a more meaningful result for correlation with processing behavior,

[2] Code name for Deltapine 15 used in the Cotton Research Project at Textile Research Institute.

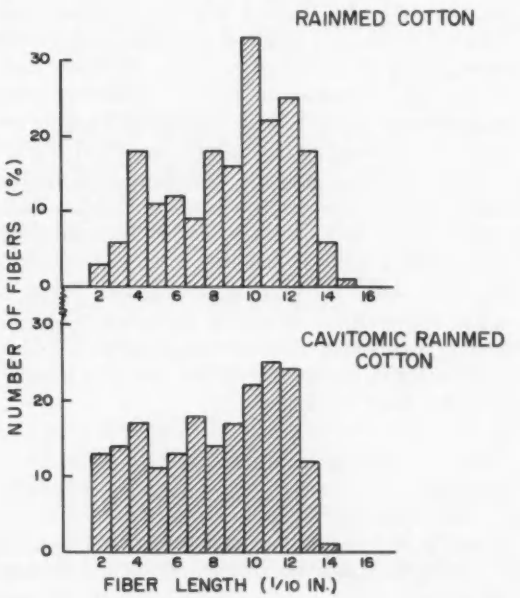


Fig. 6. Fiber length distributions for Rainmed and Cavitomic Rainmed cottons.

TABLE V. Comparison of Fiber Lengths of Rainmed Cottons Measured on the Suter Webb Sorter, the Uster Staple Apparatus, and the Fiber Length Tester

	Suter Webb Sorter*				Uster Staple Apparatus*		Fiber Length Tester†	
	Mean length (Weight av.) (in.)	Std. dev. (in.)	Mean length (Number av.) (in.)	Std. dev. (in.)	Mean length (Number av.) (in.)	Std. dev. (in.)	Mean length (Number av.) (in.)	Std. dev. (in.)
Rainmed cotton	0.98	(0.32)	0.71	(0.44)	0.83	(0.31)	0.80	(0.32)
Cavitomic Rainmed cotton	0.97	(0.31)	0.72	(0.42)	0.75	(0.29)	0.71	(0.34)

* Three pulls for Suter Webb Sorter and Uster Staple Apparatus for each mean value reported.
† 200 fibers tested on Fiber Length Tester for each mean value reported.

since it measures the actual length of each fiber tested rather than a length based on a weight average.

Acknowledgments

The authors wish to express their appreciation to Dr. J. H. Dillon, Director of Textile Research Institute, for making available funds for the construction of the Fiber Length Tester and for his continuing encouragement during the design and early testing phases of the instrument. The authors are indebted to Werner von Bergen, Director of Research of the Forstmann Woolen Company, Passaic, New Jersey, for the fiber length data on the various wool types, using the U.S.D.A. and A.S.T.M. methods; to Dr. John Menkart for many helpful suggestions in preparing the manuscript and for the length data obtained on these wools using the Fiber Length Tester; to Drs. Helmut Wakeham and Ludwig Rebenfeld for comparative length results on Rainmed cottons; and to Mrs. Louise Templeton and Mrs. Carol Piper for making the measurements on the Fiber Length Tester reported in this paper.

The wools used in this study were in part supplied by the U.S. Sheep Experiment Station, U.S.D.A., Dubois, Idaho, and in part on loan by the University of Idaho, Moscow, Idaho.

Literature Cited

1. Anderson, S. L., and Palmer, R. C., *J. Text. Inst.* **44**, T95–115 (1953).
2. A.S.T.M. Designation D519–49, 1952 Book of ASTM Standards, Part 7, 492–495 (American Society for Testing Materials, Philadelphia, Pa., 1952).
3. A.S.T.M. Designation D414–54T, 1954 Supplement to Book ASTM Standards, Part 7, 81–89 (American Society for Testing Materials, Philadelphia, Pa., 1954).
4. Daniels, H. E., *J. Text. Inst.* **33**, T137–150 (1942).
5. Honegger, E., *J. Text. Inst.* **42**, P57–74 (1951).
6. International Business Machine Corporation, *Reproducing Punches, Types 513 and 514* International Business Machines Corp., New York (1945).
7. Johnston, D. D., Ray, H. D., Manning, W. J., and Pohle, E. M., TEXTILE RESEARCH JOURNAL **21**, *757–762* (1951).
8. Menkart, J., "The Aging of Worsted Roving—The Development of an Accelerated Aging Process. Its Effect on Spinning Performance, Fiber Properties, and Assembly Properties," a report of work done under Contract No. A-1s-33801 with the United States Department of Agriculture and supervised by the Western Utilization Research Branch of the Agricultural Research Service (Textile Research Institute, Princeton, N. J., November 1955).
9. Palmer, R. C., *J. Text. Inst.* **39**, T8–22 (1948).
10. Wakeham, Helmut, TEXTILE RESEARCH JOURNAL **25**, 422–429 (1955).
11. Wakeham, H., and Wakelin, J. H., TEXTILE RESEARCH JOURNAL **20**, 605–612 (1950).
12. Wakelin, J. H., and von Bergen, W., "Final Report of Work on RMA Contract No. A-1s-30934 for the period 8 October 1948 to 7 October 1952," submitted to Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, United States Department of Agriculture (Textile Research Institute, Princeton, N. J., May 1953).

Manuscript received April 27, 1956

Physical Properties of Cotton Reacted with Beta-Propiolactone

Emilie H. Nott[1] and James N. Grant

Southern Regional Research Laboratory, New Orleans, Louisiana[2]

Abstract

Cotton yarns made from an American upland cotton were pre-extracted with either acetone or monoethanolamine. In the present investigation they were reacted with beta-propiolactone either in the presence of xylene by the reflux method, or in the presence of either 8 or 15% sodium hydroxide by the alkali method to secure add-ons in weight of up to 36.9%. A new type of modified cotton produced by graft polymerization was attained by the reaction. Certain physical properties of the fibers and yarns were measured. The changes in most properties were found to be associated with the pretreatment, the method of reaction, and the add-on of beta-propiolactone. While tenacities of fibers and yarns generally decreased progressively with increase of beta-propiolactone add-on, the decreases are due principally to the add-on of the polymer. Density decreased linearly with add-on but varied depending on pre-extraction solvents and methods of treatment used. The rate of degradation of the cellulose by heat was slightly greater in the reacted yarns than in the untreated. Frictional resistance of yarns against steel was increased for yarns reacted with beta-propiolactone in the presence of xylene, but unaffected when the alkali method was used. Electron micrographs show the polymer on the surface of those fibers reacted in xylene but very little on the surface of those reacted in alkali. Elastic recovery increased 11 to 13% with beta-propiolactone treatments.

WOOL hairs have been reacted with beta-propiolactone (BPL) and their physical properties reported by Jones and Lundgren [10] and by Fearnley and Speakman [8]. Recently the reaction has been applied to cotton cellulose at this Laboratory by Daul et al. [5 through 7], and add-ons of up to 224.5% obtained. The add-on involves chemical attachment of carboxyethyl ether or hydroxypropionate ester groups to the cellulose followed by graft polymerization. This process of graft polymerization offers a new method for chemically treating cotton to secure a cellulose of different physical properties and for further chemical treatment. While the treatment with beta-propiolactone was found to alter several properties of the cellulose, the reacted cellulose offers possibilities of a new field of investigation. The effects of such treatments on certain physical and chemical properties of yarns and fabrics are reported in the final article by Reinhardt et al. [15].

[1] Resigned.

[2] One of the laboratories of the Southern Utilization Research Branch, Agricultural Research Service, United States Department of Agriculture.

The present investigation was undertaken to determine the changes in physical properties of fibers and yarns, attained by the xylene reflux and alkali methods of reaction, for add-ons ranging from 0 to 36.9%. In most instances the reaction alters the physical properties of both fibers and yarns, the changes being dependent upon the pretreatment, methods of reaction, and per cent add-on of beta-propiolactone.

Experimental Procedure

Samples

The three-ply yarns used in the study were processed from a Deltapine cotton of average fiber characteristics. Yarn number, direction of twist, and turns per inch were designated by 14:Z11.2/3:S6.5 and 14:Z15.3/3:S8.9 for yarns of the two different constructions [1]. A sufficient number of 120-yd. skeins from each construction were prepared for use as controls of pretreatments and for reaction with BPL. As no differences in results were found for the two constructions, the values given in this paper are for yarns of 14:Z11.2/3:S6.5 construction. As

since it measures the actual length of each fiber tested rather than a length based on a weight average.

Acknowledgments

The authors wish to express their appreciation to Dr. J. H. Dillon, Director of Textile Research Institute, for making available funds for the construction of the Fiber Length Tester and for his continuing encouragement during the design and early testing phases of the instrument. The authors are indebted to Werner von Bergen, Director of Research of the Forstmann Woolen Company, Passaic, New Jersey, for the fiber length data on the various wool types, using the U.S.D.A. and A.S.T.M. methods; to Dr. John Menkart for many helpful suggestions in preparing the manuscript and for the length data obtained on these wools using the Fiber Length Tester; to Drs. Helmut Wakeham and Ludwig Rebenfeld for comparative length results on Rainmed cottons; and to Mrs. Louise Templeton and Mrs. Carol Piper for making the measurements on the Fiber Length Tester reported in this paper.

The wools used in this study were in part supplied by the U.S. Sheep Experiment Station, U.S.D.A., Dubois, Idaho, and in part on loan by the University of Idaho, Moscow, Idaho.

Literature Cited

1. Anderson, S. L., and Palmer, R. C., *J. Text. Inst.* **44**, T95–115 (1953).
2. A.S.T.M. Designation D519–49, 1952 Book of ASTM Standards, Part 7, 492–495 (American Society for Testing Materials, Philadelphia, Pa., 1952).
3. A.S.T.M. Designation D414–54T, 1954 Supplement to Book ASTM Standards, Part 7, 81–89 (American Society for Testing Materials, Philadelphia, Pa., 1954).
4. Daniels, H. E., *J. Text. Inst.* **33**, T137–150 (1942).
5. Honegger, E., *J. Text. Inst.* **42**, P57–74 (1951).
6. International Business Machine Corporation, *Reproducing Punches, Types 513 and 514* International Business Machines Corp., New York (1945).
7. Johnston, D. D., Ray, H. D., Manning, W. J., and Pohle, E. M., TEXTILE RESEARCH JOURNAL **21**, 757–762 (1951).
8. Menkart, J., "The Aging of Worsted Roving—The Development of an Accelerated Aging Process. Its Effect on Spinning Performance, Fiber Properties, and Assembly Properties," a report of work done under Contract No. A-1s-33801 with the United States Department of Agriculture and supervised by the Western Utilization Research Branch of the Agricultural Research Service (Textile Research Institute, Princeton, N. J., November 1955).
9. Palmer, R. C., *J. Text. Inst.* **39**, T8–22 (1948).
10. Wakeham, Helmut, TEXTILE RESEARCH JOURNAL **25**, 422–429 (1955).
11. Wakeham, H., and Wakelin, J. H., TEXTILE RESEARCH JOURNAL **20**, 605–612 (1950).
12. Wakelin, J. H., and von Bergen, W., "Final Report of Work on RMA Contract No. A-1s-30934 for the period 8 October 1948 to 7 October 1952," submitted to Bureau of Agricultural and Industrial Chemistry, Agricultural Research Administration, United States Department of Agriculture (Textile Research Institute, Princeton, N. J., May 1953).

Manuscript received April 27, 1956

Physical Properties of Cotton Reacted with Beta-Propiolactone

Emilie H. Nott[1] and James N. Grant

Southern Regional Research Laboratory, New Orleans, Louisiana[2]

Abstract

Cotton yarns made from an American upland cotton were pre-extracted with either acetone or monoethanolamine. In the present investigation they were reacted with beta-propiolactone either in the presence of xylene by the reflux method, or in the presence of either 8 or 15% sodium hydroxide by the alkali method to secure add-ons in weight of up to 36.9%. A new type of modified cotton produced by graft polymerization was attained by the reaction. Certain physical properties of the fibers and yarns were measured. The changes in most properties were found to be associated with the pretreatment, the method of reaction, and the add-on of beta-propiolactone. While tenacities of fibers and yarns generally decreased progressively with increase of beta-propiolactone add-on, the decreases are due principally to the add-on of the polymer. Density decreased linearly with add-on but varied depending on pre-extraction solvents and methods of treatment used. The rate of degradation of the cellulose by heat was slightly greater in the reacted yarns than in the untreated. Frictional resistance of yarns against steel was increased for yarns reacted with beta-propiolactone in the presence of xylene, but unaffected when the alkali method was used. Electron micrographs show the polymer on the surface of those fibers reacted in xylene but very little on the surface of those reacted in alkali. Elastic recovery increased 11 to 13% with beta-propiolactone treatments.

WOOL hairs have been reacted with beta-propiolactone (BPL) and their physical properties reported by Jones and Lundgren [10] and by Fearnley and Speakman [8]. Recently the reaction has been applied to cotton cellulose at this Laboratory by Daul et al. [5 through 7], and add-ons of up to 224.5% obtained. The add-on involves chemical attachment of carboxyethyl ether or hydroxypropionate ester groups to the cellulose followed by graft polymerization. This process of graft polymerization offers a new method for chemically treating cotton to secure a cellulose of different physical properties and for further chemical treatment. While the treatment with beta-propiolactone was found to alter several properties of the cellulose, the reacted cellulose offers possibilities of a new field of investigation. The effects of such treatments on certain physical and chemical properties of yarns and fabrics are reported in the final article by Reinhardt et al. [15].

[1] Resigned.

[2] One of the laboratories of the Southern Utilization Research Branch, Agricultural Research Service, United States Department of Agriculture.

The present investigation was undertaken to determine the changes in physical properties of fibers and yarns, attained by the xylene reflux and alkali methods of reaction, for add-ons ranging from 0 to 36.9%. In most instances the reaction alters the physical properties of both fibers and yarns, the changes being dependent upon the pretreatment, methods of reaction, and per cent add-on of beta-propiolactone.

Experimental Procedure

Samples

The three-ply yarns used in the study were processed from a Deltapine cotton of average fiber characteristics. Yarn number, direction of twist, and turns per inch were designated by 14:Z11.2/3:S6.5 and 14:Z15.3/3:S8.9 for yarns of the two different constructions [1]. A sufficient number of 120-yd. skeins from each construction were prepared for use as controls of pretreatments and for reaction with BPL. As no differences in results were found for the two constructions, the values given in this paper are for yarns of 14:Z11.2/3:S6.5 construction. As

a pretreatment, all yarns were extracted in a Soxhlet extractor for about 6 hr. either with acetone or with monoethanolamine. In referring to samples, yarns will be identified both by the pre-extraction liquid used and conditions of reaction following this pretreatment.

Fibers for the single fiber measurements were obtained by defibering the extracted or treated yarns. For each sample the fibers were then taken at random from the modal group of a length distribution.

Treatments

The pretreated yarns were reacted with BPL, in most cases without tension, using either the xylene reflux or the alkali methods, described by Daul et al. [5, 6, 7]. In what will hereafter be referred to as the xylene reflux method, xylene was the organic medium or diluent used; and in the alkali method either 8 or 15% solutions of sodium hydroxide were padded on the yarns before reaction. Following the reaction, all yarns were given a 6-hr. acetone extraction in a Soxhlet extractor to remove any unlinked polymer and unreacted BPL. However, the phrase "acetone extraction" will ordinarily refer to the pretreatment of the yarn rather than to the subsequent extraction to remove unreacted polymer.

Test Methods

Fibers and yarns were exposed six weeks in a standard atmosphere (70° F., 65% R.H.) to assure moisture equilibrium. After this period of conditioning, specimens were tested for breaking load, elongation at break, moisture regain, and shrinkage. Tests for wet breaking load and hot breaking load of yarns were made in a standard atmosphere but under the special conditions which will be described in the discussion of these tests.

Strength, elongation, and moisture regain (oven dry) measurements on yarns were made according to A.S.T.M. methods [2, 3]. However, all tensile and elastic measurements of fibers and yarns were made with the TRI-Schaevitz [2] electronic tester [14].

The tenacities and elongations at break of the single fibers were obtained from measurements on 200 fibers from each sample. Length of fiber specimen between clamps was 0.78 cm. and average time required to break each fiber specimen was about 18 sec.

[2] The mention of trade names does not imply their endorsement by the Department of Agriculture over similar products not mentioned.

The shrinkage in length of fibers due to treatment was determined from the upper quartile values of the length distribution; that of yarns was calculated from the average length of 10 specimens, taken at random from cut skeins of treated and untreated yarns, and measured while under load of 28.5 g. Other procedures in fiber testing followed those described in previous investigations [11, 12].

Density measurements were made with the density gradient column, using the techniques described in a previous article [13].

The resistance to heat was determined from strength measurements of yarns which were washed in slightly alkaline water, then heat-degraded for 48 hr. at 160° C. Yarns were reconditioned in a standard atmosphere for 7 days before tensile measurements were made.

The coefficient of friction of the yarns was determined with a modification of the apparatus used by Buckle and Pollitt [4]. The yarn, which was attached to the load cell of the electronic tester, passed in a 90° angle around a polished stainless steel cylinder of 1.5-in. diameter, then over a pulley and was loaded at the free end with a 28.5-g. weight. The rate of traverse of yarn over the cylinder was 20 in./min.

Results and Discussion

Properties of Fibers

In Table I is given the identification of samples by their pre-extraction and reaction treatment along with the add-on weight acquired during the reaction. Also given are breaking load and elongation at break, tenacity, and lengths of fibers expressed as percentages of the values of their controls.

Breaking load. A comparison of the effects of pre-extraction on fibers indicated that the breaking loads of fibers extracted with ethanolamine were less than those extracted with acetone. The reaction of these fibers with BPL by the xylene reflux method following either pre-extraction agent caused an additional decrease in the breaking loads, ranging from 23 to 30%. Reaction of the yarn with BPL in the presence of 15% NaOH also caused a decrease (4%) from the NaOH control, although both had breaking loads greater than that of the acetone pre-extracted control.

Elongation at break. The elongation at break of fibers was decreased from the respective controls when reacted with BPL by either the xylene reflux

or the alkali methods of treatment. However, those fibers swollen with NaOH, or reacted with BPL in the presence of NaOH, had greater elongations than did the acetone control. The trends shown by elongation were to be expected because of swelling effects of the caustic or the changes in values of the breaking loads.

Tenacity. Tenacities of fibers reacted with BPL also showed a decrease from that of the pre-extracted controls. No increase in tenacity was found for the alkali control, as had been found for breaking load and elongation at break; reaction with BPL in presence of alkali decreased tenacity about 13%. This decrease is attributed to the add-on in weight, and not to the degradation of the cellulose, since, if adjusted for add-on weight of BPL and moisture regain, tenacity was not decreased.

Length. Fiber length, like breaking load and tenacity, was less for those fibers pre-extracted with ethanolamine than with acetone. However, little change can be attributed to the BPL reaction. The decreases in length of the alkali-treated fibers were about 15%, which is the contraction expected for loose mercerized fibers.

Properties of Yarns

In Table II are given sample treatments, add-on of weight, moisture regain, shrinkage, elongation at break, and tenacity for the low twist yarns. Measurements were also made on medium twist yarns which were reacted by the xylene reflux method, but trends for these yarns followed those of low twist yarns so closely that the changes will not be discussed.

Moisture regain. In both xylene reflux and alkali-conducted reactions, moisture regains decreased progressively and linearly with increase of BPL add-on. The regains for the controls of the alkali-reacted samples approximated those of normal alkali-swollen cotton, while those of the xylene reflux controls were essentially the regains of untreated cotton. Moisture reductions, calculated on dry sample weight, were slightly greater than those explainable by the addition of nonhygroscopic polymers. However, similar discrepancies in regains for wool, reacted with BPL, have been explained [10] either by a chemical reaction yielding a product with lower moisture regain or by the blocking of areas normally accessible to moisture.

Yarn shrinkage. The lengths of sections of yarn after either acetone or ethanolamine extraction were found to be less than those of the untreated sections. For the acetone-extracted yarn the shrinkage was 1.9% while for those extracted with ethanolamine the shrinkage was 4.5%. This is the same trend that was shown by single fiber shrinkage. Additional samples of yarn of other percentage add-ons were tested to confirm the relations shown by the fibers. If the weight gains were large, further shrinkages were found in acetone-extracted but not in ethanolamine-extracted yarns, or with either acetone- or ethanolamine-extracted yarns if reacted with alkali. The shrinkages of yarns reacted with

TABLE I. Physical Properties of Beta-Propiolactone-Reacted Single Fibers Expressed as Percentages of Those of the Controls

Sample treatment	Add-on weight (%)	Breaking load (%)	Elongation at break (%)	Tenacity (%)	Length U.Q. (%)
Acetone-extracted					
Control	0.0	100 (6.1 g.)	100 (10.9%)	100 (2.9 g./grex)	100 (1.29 in.)
Xylene reflux method					
BPL-reacted	20.3	77	90	73	98
Alkali method					
Control (15% NaOH)	0.0	100 (6.9 g.)	100 (17.2%)	100 (2.9 g./grex)	100 (1.11 in.)
BPL-reacted (15% NaOH)	17.2	96	83	87	103
Ethanolamine-extracted					
Control	0.0	100 (5.5 g.)	100 (11.0%)	100 (2.7 g./grex)	100 (1.23 in.)
Xylene reflux method					
BPL-reacted	12.3	70	71	63	99
BPL-reacted (with tension)	18.5	74	75	68	101

TABLE II. Properties of Low Twist Untreated and Control Yarns and Yarns Reacted with Beta-Propiolactone

Sample treatment	Add-on weight (%)	Moisture regain (%)	Shrinkage of length (%)	Elongation at break (%)	Tenacity (g./grex)
Untreated yarns	0.0	6.3	0.0	8.0	1.6
Acetone-extracted					
Xylene reflux method					
Control (xylene)	0.0	6.3	1.9	8.6	2.1
BPL-reacted	3.2	5.9	1.9	9.0	1.9
BPL-reacted	8.6	5.5	1.5	8.9	1.7
BPL-reacted	20.3	4.6	2.6	8.5	1.4
BPL-reacted	26.5	4.3	2.5	7.7	1.3
Alkali method					
Control (8% NaOH)	0.0	7.4	5.1	10.4	2.0
BPL-reacted (8% NaOH)	10.8	6.3	4.2	9.5	1.7
Control (15% NaOH)	0.0	10.1	19.0	18.5	1.8
BPL-reacted (15% NaOH)	17.2	9.3	16.0	17.1	1.5
Ethanolamine-extracted					
Xylene reflux method					
Control (xylene)	0.0	6.1	4.5	9.7	1.9
BPL-reacted	7.3	5.4	3.5	7.8	1.4
BPL-reacted	12.3	4.0	3.7	6.0	0.8
BPL-reacted (with tension)	18.5	4.5	2.9	6.8	1.1
BPL-reacted	31.7	2.8	4.3	5.5	0.6
Alkali method					
Control (8% NaOH)	0.0	6.7	5.7	10.9	1.8
BPL-reacted (8% NaOH)	20.2	5.8	5.1	6.0	0.7
Control (15% NaOH)	0.0	9.1	20.9	19.6	1.7
BPL-reacted (15% NaOH)	29.4	8.0	20.3	16.8	1.0

BPL in the presence of alkali were always less than those of the yarns which were only treated with the alkali.

Elongation at break. The elongations at break of those yarns pre-extracted with acetone and reacted in the presence of xylene were essentially equal to that of the control, while all other yarns showed a decrease. Elongation at break of yarns treated in 15% NaOH had values approaching those for loose mercerized yarns. When yarns had a decrease in breaking load caused by the reaction with BPL, a decrease was also found in elongation.

Tenacity. The tenacities of all yarns reacted with BPL were found to decrease as the add-on increased. Decreases in tenacity, however, were greater than the amount which could be accounted for by the added weight. In Figure 1 are shown the decreases in tenacity of cellulose on dry basis when corrected for the added weight of BPL and moisture regain and plotted against the add-on of BPL. Except for the acetone-extracted sample reacted in the presence of 15% NaOH, which had tenacity equal to that of the control, all samples had tenacities less than those of the controls. The loss in tenacity by fabrics, which were reacted with BPL in the presence of the 15% NaOH, was observed by Reinhardt et al. [15]. They also found, on the basis of fluidity measurements, that the alkali method does not cause as much cellulose damage as the xylene reflux method.

Elastic recovery. The elastic recovery (given in Table III) from loads equivalent to 25% of the breaking loads of the controls was measured on yarns

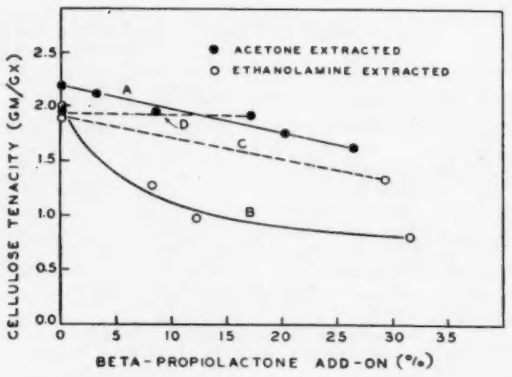


Fig. 1. The relationship of cellulose tenacity (corrected for BPL add-on of yarns to BPL add-on in modified yarns reacted by xylene reflux method (curves *A* and *B*) and 15% alkali method (curves *C* and *D*).

reacted with BPL by both the xylene reflux and alkali methods. Recovery after 1-min. relaxation was 11 and 13% greater for BPL-reacted than for control yarns by the xylene reflux and alkali methods, respectively. While these increases are small, it is evident that reaction with BPL by both methods increases the elastic recovery of the materials.

Strength of wet yarns. Table IV gives the breaking loads of wet yarns which were allowed to absorb water during the 16 hr. prior to testing, expressed as a percentage of the breaking loads at standard conditions. All yarn strengths were increased slightly by wetting except those of the alkali-reacted cotton which were decreased by wetting.

Strength of hot yarns. Also, Table IV gives the breaking loads of yarns, tested at 115° C., which is above the melting point of lactone polymer. The yarns were heated 10 min. before testing. The strengths retained by the yarns pre-extracted by acetone were somewhat greater than those pre-extracted with ethanolamine. This was true both for controls and for samples reacted with BPL by either method.

TABLE III. Elastic Recovery of Beta-Propiolactone-Reacted Yarns from Stresses Equal to 25% of the Breaking Load

Sample treatment	Add-on weight (%)	Elastic recovery (%)
Acetone-extracted		
Control	0.0	3.65
BPL-Xylene-reacted	20.3	4.05
Control (15% NaOH)	0.0	5.00
BPL-alkali-reacted (15% NaOH)	17.2	5.65

TABLE IV. Wet and Hot Breaking Loads of Pre-extracted Yarns before and after Reaction with Beta-Propiolactone by Two Methods

Sample treatment	Add-on weight (%)	Breaking load*	
		Wet (%)	Heated to 115° C. (%)
Acetone-extracted			
Alkali method			
Control (15% NaOH)	0.0	104	77
BPL-reacted	17.2	80	77
Ethanolamine-extracted			
Xylene reflux method			
Control	0.0	107	61
BPL-reacted	8.3	122	69
BPL-reacted	31.7	105	—

* Expressed as percentages of breaking loads of yarns in moisture equilibrium with atmosphere at standard conditions.

TABLE V. The Tenacity Retained After Heating at 160° C. for 48 Hr. and Alkalinity of the Rinse Water of Yarns Reacted under Various Conditions with Beta-Propiolactone

Sample treatment	Add-on weight (%)	Tenacity retained (%)	pH of wash water
Acetone-extracted			
Xylene reflux method			
Control (xylene)	0.0	43	9.1
BPL-reacted	3.2	32	7.4
BPL-reacted	8.6	31	7.3
BPL-reacted	20.3	27	7.9
Alkali method			
Control (8% NaOH)	0.0	40	8.2
BPL-reacted (8% NaOH)	10.8	41	7.2
Control (15% NaOH)	0.0	60	7.9
BPL-reacted (15% NaOH)	17.2	46	7.0
Ethanolamine extracted			
Xylene reflux method			
Control (xylene)	0.0	38	8.6
BPL-reacted	8.3	22	7.1
BPL-reacted	31.7	24	7.0
Alkali method			
Control (8% NaOH)	0.0	39	8.0
BPL-reacted (8% NaOH)	20.2	29	7.0
Control (15% NaOH)	0.0	45	8.3
BPL-reacted (15% NaOH)	29.4	17	7.2

Heat degradation. Table V gives the tenacities, expressed as percentages of the tenacities of the untreated yarns, of the controls and reacted yarns after heat degradation for 48 hr. at 160° C. The strength retained by the reacted yarns was less than that of the control in all cases, with the exception of the sample pre-extracted with acetone and reacted with BPL in the presence of 8% sodium hydroxide. In this yarn, the strength retained was equal to that of the control. The strengths retained by the BPL-reacted yarns averaged about 10% less than those of their controls, while strengths of yarns pre-extracted with ethanolamine were about 5% less than those pre-extracted with acetone. The yarns pre-extracted with acetone and then reacted with BPL by the alkali method offered the only possibility of a product resistant to heat degradation with strength retention equivalent to that of the untreated cotton. The greater degradation of the reacted yarns has been attributed to tendering, due to the acidity of these yarns at the time of heating [15].

Even though considerable scatter was found in the relation of strength retained to pH values of the water in which the yarns were rinsed, it was evident

TABLE VI. Coefficients of Friction of Beta-Propiolactone-Reacted Yarns Expressed as Percentages of that of the Ethanolamine-Extracted Control

Sample treatment	Add-on weight (%)	Coefficient of friction (%)
Ethanolamine-extracted		
Control	0.0	100
Xylene reflux method		
Control (xylene)	0.0	95
BPL-reacted	12.3	136
BPL-reacted (with tension)	18.5	132
BPL-reacted	31.7	189
Alkali method		
Control (8% NaOH)	0.0	94
BPL-reacted (8% NaOH)	29.4	97

that the samples treated according to prescribed methods and later extracted with acetone contained constituents which reduced alkalinity of the water. When wash water with initial pH of 10 was used, its final pH values ranged from 7.9 to 9.1 for the controls and from 7.0 to 8.1 for the BPL-reacted yarns. In other tests, the effect of pH of rinse water on heat resistance of BPL yarns was studied in the range from 2.6 to 10.5 pH. The BPL-reacted yarns showed consistently less heat resistance than the untreated yarns over the whole range.

Frictional properties. Frictional resistance of yarns reacted by the xylene reflux method to add-on weights of 12.3 to 31.7% were measured against stainless steel. The frictional resistance, expressed as percentages of the ethanolamine-extracted control (Table VI), was found to vary from 95 to 189%, depending on the add-on and conditions of treatment. On the other hand, yarns reacted by the alkali method showed no essential change in friction from that of the alkali-treated control. This is consistent with results on abrasion resistance of fabrics reported by Reinhardt et al. [15]. They found that the abrasion resistance of fabrics reacted by the alkali method differed only slightly from that of the alkali-treated control. However, contrary to the present data on yarns, abrasion resistance of fabrics reacted with BPL by the xylene reflux method was reported to have decreased.

Electron micrographs of replicas of surfaces of fibers [9] reacted by the xylene reflux method (Figure 2) have shown that the polymer extends to the surface for add-ons of 18.5 and 31.7%, but is not visible in appreciable amounts on the surface of fibers which were reacted by the alkali method with add-ons of 20.2 and 29.4%. The increased friction and lower abrasion resistance of the yarns reacted in xylene have been attributed to the differences in surface characteristics.

Density. The relations between density of the reacted cotton and the add-on of BPL are shown in Figure 3. In these observations, densities for yarns of both constructions are included since no differ-

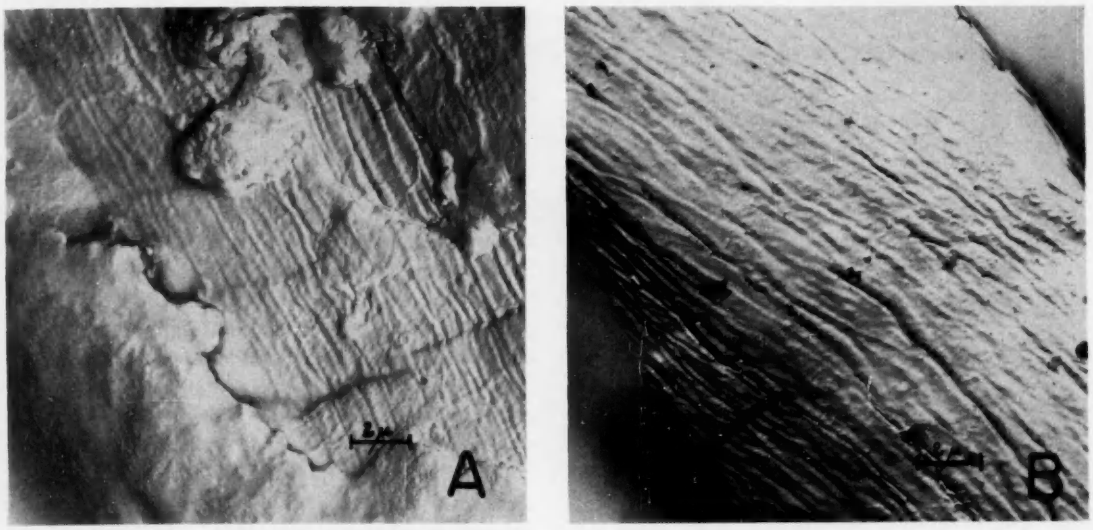


Fig. 2. Electron micrographs of ethanolamine-extracted fibers showing the polymer on the surface of the xylene-reacted fiber (*A*) and smaller amounts on the surface of the sodium hydroxide–reacted fiber (*B*). 6000×.

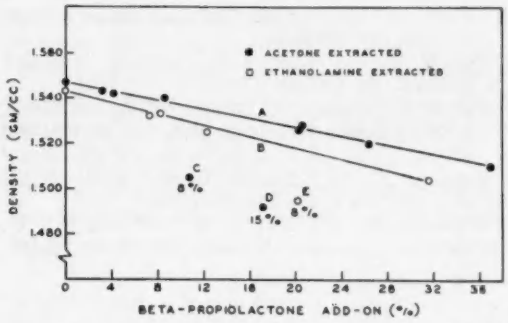


Fig. 3. The relationships of density to beta-propiolactone add-on in modified yarns reacted by the xylene reflux (curves *A* and *B*) and the alkali methods (points *C*, *D*, and *E*).

ences in density, due to construction, were observed. The densities decreased approximately linearly as the add-on increased. For the yarns reacted in xylene, the densities of those pre-extracted in acetone were consistently higher than those pre-extracted in ethanolamine. However, for the yarns reacted in alkali, the densities of those pre-extracted in ethanolamine were higher than those pre-extracted in acetone. When the extracted control yarns were boiled in water and dried, the differences in density were partially but not completely removed by an increase in density of the ethanolamine-extracted yarn. Causes for differences in densities of ethanolamine- and acetone-extracted yarns are not at present fully understood; but in those reacted in xylene the differences are attributed in part to occlusion of molecules of ethanolamine in the cellulose and swelling during extraction. Densities lower than that of untreated cotton were reported by Orr et al. [13] for cottons following swelling in water, solvent exchanging, and air drying. The lower densities of yarns reacted in alkali as compared with those reacted in xylene is considered due to the different chemical compounds formed by the two methods of reaction [7].

Summary

Measurements of certain physical properties of fibers taken from yarns reacted with beta-propiolactone either in xylene or in aqueous alkali, have shown that shrinkage in length occurs during the reaction, especially in alkali, and that the linear density is changed by three factors: add-on in weight, shrinkage in length, and loss of moisture-absorbing capacities. Tenacities of single fibers were decreased more than can be accounted for merely by change in linear density, thus indicating that the reaction of cotton with BPL causes a degradative effect on the cellulose. The loss in tenacity of fibers was confirmed by corresponding losses in tenacity of yarns. Elongations at break of fibers and yarns were increased as a result of shrinkage in length, but considerable decreases were observed when losses of strength occurred.

Moisture regain was reduced gradually with increased add-on of BPL, but was slightly more than that calculated from the addition of weight of a nonhygroscopic material. Density of the cellulose decreased linearly with add-on but differences in density were found, due to solvents used for pre-extraction and to methods of reaction.

Elastic recovery was slightly improved but probably not sufficiently to become an important factor in the use of the material. While frictional resistance against steel of the yarns reacted in xylene was increased over that of the acetone-extracted control, friction of the yarns reacted in alkali was essentially unchanged. The increased friction has been attributed to the polymer attached to the surface of the cotton reacted by the xylene reflux method.

While under the conditions applied the treatments were not, in general, beneficial to the textile properties of cotton, they did supply a chemical modified starting material for many types of further chemical modification to produce new and possibly valuable textile fibers.

Acknowledgments

The authors wish to express their appreciation to members of the Cotton Mechanical Processing Unit for processing the yarns; to George C. Daul, Robert M. Reinhardt, and J. David Reid for preparation and chemical analyses of samples; to Anna T. Moore and Verne W. Tripp for electron micrographs; and to Betty A. Burrow and Albert W. Burgis for assistance in the measurement of physical properties of yarns.

Literature Cited

1. ASTM D1244–53T, American Society for Testing Materials, Philadelphia, Pa.
2. *Ibid.*, D180–54T.
3. *Ibid.*, D629–54T.
4. Buckle, H., and Pollitt, J., *Shirley Inst. Memoirs* **22**, 1–12 (1948); and *J. Textile Inst.* **39**, T199–210 (1948).
5. Daul, G. C., Reinhardt, R. M., and Reid, J. D., TEXTILE RESEARCH JOURNAL **24**, 738–743 (1954).

6. Daul, G. C., Reinhardt, R. M., and Reid, J. D., TEXTILE RESEARCH JOURNAL **24**, 744–747 (1954).
7. Daul, G. C., Reinhardt, R. M., and Reid, J. D., TEXTILE RESEARCH JOURNAL **25**, 330–333 (1955).
8. Fearnley, C., and Speakman, J. B., *J. Soc. Dyers Colourists* **68**, 88–91 (1952).
9. Hall, C. E., *Introduction to Electron Microscopy*, McGraw-Hill Book Co., Inc., New York (1953).
10. Jones, H. W., and Lundgren, H. P., TEXTILE RESEARCH JOURNAL **21**, 620–634 (1951).
11. McDonald, A. W., Humphreys, G. C., Kromhout, O. M., and Grant, J. N., TEXTILE RESEARCH JOURNAL **26**, 641 (1956).
12. Orr, R. S., and Grant, J. N., TEXTILE RESEARCH JOURNAL **23**, 505–509 (1953).
13. Orr, R. S., Weiss, L. C., Moore, H. B., and Grant, J. N., TEXTILE RESEARCH JOURNAL **25**, 592–600 (1955).
14. Reichardt, C. H., Schaevitz, H., and Dillon, J. H., *Rev. Sci. Instr.* **20**, 509–516 (1949).
15. Reinhardt, R. M., Reid, J. D., and Daul, G. C., TEXTILE RESEARCH JOURNAL **26**, 74–80 (1956).

Manuscript received March 26, 1956.

Letters to the Editor

Effect of Laundering on Shirts

American Institute of Laundering
Joliet, Illinois
March 5, 1956

To the Editor
TEXTILE RESEARCH JOURNAL

Dear Sir:

We have read with a great deal of interest the Letter to the Editor titled "Effect of Laundering on Shirts," by Mary Anna Grimes and Carolyn A. Werman, on pages 112 and 113 in the February issue of TEXTILE RESEARCH JOURNAL. In this report the authors present the results of launderings by three commercial laundries and by two household methods. We offer below some observations based on 34 years of washroom-textile experience with our member laundries, now numbering a total of 3000.

Concerning home washing methods it is perhaps obvious that results under such conditions will vary widely. We know of one excellent study conducted in 15 homes under the observations of technicians (not our own). After 50 washings the whiteness retention was found to range from a high of 99.9% to a low of 79.4%. The breaking strength losses range from 9.1% to 70.2%.

Every year our laboratory division sends thousands of test pieces to our member plants. These plants launder these white cotton percale samples 20 times in whatever washing process they are studying and return them to our laboratories for grading and comment. In 1955 we received 2004 test pieces that had been laundered repeatedly with white shirts (soiled and not clean). The average tensile strength loss was 9.4% and the whiteness retention 96.6%.

In the home washing tests reported by Grimes and Werman, the shirts (washed without bleach) were laundered in the absence of soil. In our commercial laundry tests the shirts were washed with soiled garments, necessitating the addition of hypochlorite solution to eliminate oxidizable soil. It was reported as long ago as 1934 [1] that white cotton test pieces washed with soiled loads of white work gradually become gray *without* the use of bleach and that the addition of 2 qt. of 1% available chlorine stock solution to a 100-lb. load (200 dress shirts by the way) is good practice in that improved whiteness is obtained and tensile strength losses are kept under 10% for a total of 20 launderings.

As a case in point, let us consider the daily operations of our own Commercial Laundry Department operated by the Institute for the general population of the Joliet area for the month of February. During that month we laundered 39,549 regular dress shirts and 6338 sport shirts. In four weeks' times our girls missed 24 buttons (all others were undamaged or had been replaced) on these 39,549 dress shirts. Since each shirt carries an average of 8 buttons, the grand total of shirt buttons processed in this particular month was 316,392. In addition we had four color fastness and one shrinkage complaint on sport

[1] A.I.L. Special Report 53, "Influence of Bleaching on the Whiteness and Tensile Strength of Cotton Fabrics" (1934).

shirts, which is not a bad record considering the blends of fibers used in sportwear these days.

We have conducted also scores of laundry-wear tests with shirts, using our own staff people as wearers of the garments. We have observed that shirts which showed no evidence of wear after 100 or more launderings without being worn in between, showed decided wear in from 30 to 46 launderings, depending upon the individual who wore the shirt. Wear is a factor in the life of any garment and can be demonstrated by conducting comparative tensile strength tests on the shoulders of a worn-out shirt or other garment in comparison with the shirttail area of the same material.

In the matter of shrinkage it has been the general experience that with the advent of Sanforizing and similar processes, the shrinkage of collars or the sleeves of dress shirts has no longer become a factor. Nevertheless, the Texas A. and M. letter stresses the fact that after 68 launderings the shrinkage in the three commercial laundries ranged from 3.4 to 3.8%, and in the household laundering with hand ironing, it was 1.7%. Did the collars shrink below the stamped collar size of the shirt?

To conclude, we do not contend that commercial laundries are perfect. Nevertheless, from our experience we are led to believe that the case for commercial laundries is not so black as might be inferred from the study at Texas A. and M.

GEORGE H. JOHNSON

Texas Agricultural Experiment Station
Texas A and M College
College Station, Texas
March 26, 1956

To the Editor
TEXTILE RESEARCH JOURNAL

Dear Sir:

This is in answer to questions raised by George H. Johnson of the American Institute of Laundering concerning the letter on effect of laundering on shirts, which appeared as a Letter to the Editor in the February issue of TEXTILE RESEARCH JOURNAL.

The Institute reports that test pieces lost an average of 9.4% in strength after 20 launderings in their member plants. Assuming that the loss is progressive, after 68 launderings test pieces would have lost an average of approximately 32%. Then in comparison, it seems that an average loss of 26% after 68 launderings in the three laundries in our study is small. Even the laundry which was hardest on the shirts in our study probably caused little more loss in strength than the average of those for which the Institute checked test pieces. In this laundry the shirts lost 7% after 15 launderings and 15% after 25 launderings in comparison with 9.4% after 20 launderings of test pieces for the Institute.

Yes, the collar bands *did* shrink one size from that marked. A shrinkage of 3.4 to 3.8% in the collar bands of shirts which were stamped and which originally measured size 15, reduced them by 0.51 to 0.57 in. from a size 15 to a 14½. This shrinkage was enough to cause moving of buttons and requests for a larger size by men who wore shirts of the same fabrics in a serviceability study. As stated, these sanforized shirts, even when home-laundered, shrank more than 1%. This shrinkage probably accounts for no loss of strength in the household-laundered shirts.

In two of the commercial laundries and in the laboratory laundry, the shirts became whiter as laundering progressed. In one laundry they became noticeably more yellow. In a study nearing completion, shirts which were worn and badly soiled were laundered in the laboratory. After 30 launderings without bleach the shirts had retained 98% of their original whiteness.

The laundries were not told that a comparison of laundries and laundry methods would be made. They knew only that shrinkage would be measured.

Not all of these laundries were member plants of the Institute. It is not known how closely they followed procedures recommended by the Institute of Laundering, nor if the workers were as closely supervised as those of the laundry at the Institute undoubtedly are. However, the counterpart of the services of these laundries must be available in many sections of the country.

As stated in an earlier report it is quite possible that the techniques used in the laboratory were better controlled and less drastic than those used in some households.

MARY ANNA GRIMES
CAROLYN A. WERMAN

Breaking Strength of Cotton Fiber Bundles

Technological Laboratory
Indian Central Cotton Committee
Matunga, Bombay 19, India
May 14, 1956

To the Editor
TEXTILE RESEARCH JOURNAL

Dear Sir:

I have read with much interest the paper entitled "Breaking Strength of Twisted Bundles of Jute Fiber and Its Relation to Spinning Quality" by B. K. Chakrabarti [3] and your editorial note on it in the January 1956 issue of the Journal. I think it would be of interest to bring to the notice of the workers in this field similar work on cotton fibers which was started at this laboratory in 1951, a brief mention of which has been made in the Annual Report [1] of the Director, Technological Laboratory, 1952, and the subsequent reports. As will be seen from these published reports, extensive investigations were undertaken in order to study the relationships between yarn strength and fiber bundle strength measured at different gauge lengths of both untwisted and twisted bundles of fibers. A considerable amount of work has been done on these aspects. Attention will, however, be confined here mostly to the breaking strength of twisted bundles of cotton fibers in relation to its spinning quality.

A good deal of preliminary work done in this connection showed that it was very difficult to handle fiber bundles, especially of short staple cottons, and twist them satisfactorily for testing their breaking strength. Furthermore, a bundle is taken from a well-prepared sliver or from a bunch of fibers; one of the fiber ends is generally in the grip of the tweezer, and this practically amounts to taking a bunch of fibers with all the fibers almost aligned at one end. As such a bunch would have fiber ends at various distances from its aligned end, it would not give an idea of the fiber strength when both the ends of fibers composing the bundle are clamped. It was, therefore, decided to adopt a new method of taking fiber bundles which would simulate the lie of the fibers in a yarn; and this is briefly described below.

A small sample of cotton was selected out of the bulk by random and representative sampling. This was well cleaned by hand and made into a sliver which was passed through the draw box of the Balls Sledge Sorter [2] a number of times in order to blend the fibers and also to make them parallel to each other as far as possible. During the process of drawing, this sliver winds around a wooden roller covered with a plush which has a circumference of about 9 in. Next, the finished 9-in. sliver was again passed through the draw box, but this time, without inserting the wooden roller. As there is a draft of 4 in the draw box every time the sliver is passed through it, there is an attenuation of 4 times. In this manner, the sliver was passed a sufficient number of times through the draw box till it was reduced to the required bundle size or hank roving, as it is generally called. It should, however, be mentioned here that the initial weight of lint taken, and the size of the final sliver were so adjusted that the latter had nearly the same count as that of the yarn to which the particular cotton was spun. In other words, it was made to simulate the flat bundle of fibers which emerges out of the delivery rollers in the ring spinning frame. The attenuated sliver was next cut carefully into lengths of 1 or 1½ in., as the case may be, and each bundle was weighed and twisted in a twist tester with the desired number of turns per inch, being 4 multiplied by the square root of yarn count. This twisted bundle was next tested for breaking strength on the Scott I.P. 2 Tester at different gauge lengths using the Pressley clamps on a device made at the laboratory for this purpose. Twenty such bundles were tested for breaking strength. Strength tests were also made on the corresponding gauge lengths of untwisted bundles.

Furthermore, yarn spun out of this cotton was also similarly tested for single thread strength at different gauge lengths, namely, ¼, ⅜, ½, and 12 in.

The results obtained for eight cottons, most of them being medium-stapled, were correlated with yarn strength, and highest standard warp counts [4] and the correlation coefficients are given in Table I.

To confirm these values, a second set of 13 cottons, most of them being coarse and short stapled, was tested at two gauge lengths which had given high correlation in the first set. The correlaton coefficients obtained for these cottons are also given in Table II.

TABLE I. Correlation Coefficients between Fiber Strength of Bundles, Both Twisted and Untwisted, at Different Gauge Lengths and Yarn Strength and Spinning Value

Description of fiber bundle	Highest standard warp counts	Single thread strength: Count single thread strength product, C.S.P., test length being 12 in.	Single thread strength: Count strength product test length being 2/8 in.	3/8 in.	4/8 in.
Twisted, gauge length, in.					
2/8	0.80*	0.90†	0.86†		
3/8	0.92†	0.97†		0.98†	
4/8	0.82*	0.89†			0.79*
Untwisted, gauge length, in.					
0	0.39	0.56			
1/8	0.50	0.69			
2/8	0.53	0.66	0.63		
3/8	0.86†	0.92†		0.89†	
4/8	0.83*	0.88†			0.90†
5/8	0.86†	0.84†			

* Significant for 0.05 level. † Significant for 0.01 level.

TABLE II. Correlation Coefficients between Fiber Strength of Bundles, Both Twisted and Untwisted, at Different Gauge Lengths and Yarn Strength and Spinning Value

Description of fiber bundle	Highest standard warp counts	Single thread strength: Count single thread strength product, C.S.P., test length being 12 in.	Single thread strength: Count strength product test length being 3/8 in.	4/8 in.
Twisted, gauge length, in.				
3/8	0.77†	0.71†	0.70†	
4/8	0.76†	0.69†		0.69†
Untwisted, gauge length, in.				
3/8	0.85†	0.82†	0.74†	
4/8	0.70†	0.64*		0.81†

* Significant for 0.05 level. † Significant for 0.01 level.

It will be noticed from the values given in Table I that for the first set of cottons, the twisted bundle strength tested at $\frac{3}{8}$ in. gauge length gave very high correlation coefficients with single thread yarn strength, both for the 12 and $\frac{3}{8}$-in. test lengths, while for the second set of cottons (Table II) it gave slightly lower correlation coefficients. The correlation coefficients were, however, highly significant for both sets. It may also be observed from the values given in Tables I and II that, in most cases, there is practically little difference between the correlation coefficients obtained for the twisted and untwisted bundles. As these are based on a few values, further confirmation would be necessary. It may, however, be remarked that the technique employed for cotton in selecting a bundle and twisting it is different from that of jute. In the case of bast fibers, like jute, it will be possible to have fibers of 10-in. length or longer, but, in the case of cotton, especially the short-stapled ones, severe difficulties in selecting a proper bundle and twisting would be encountered. Therefore, it may not be possible to obtain such high correlation as has been obtained for jute.

It will, therefore, be seen from the foregoing that experiments on these lines were carried out as early as 1951 and extensive data collected in order to ascertain the relationship between the twisted fiber bundle strength and yarn strength of Indian cottons. Incidentally, it may be mentioned here that work has been done on various aspects, such as bundle strength of twisted and untwisted flat bundles of different gauge lengths and their relationships with various measures of spinning quality of Indian cottons, singly, as well as in combination with other important fiber characters. As in certain cases, the correlation coefficients were small, it was thought desirable to divide the cottons into their botanical species and work out the correlation coefficients in different combina-

tions with other important fiber characters. This has been done and some interesting results obtained. It is proposed to publish a detailed account of these investigations shortly.

C. NANJUNDAYYA

Literature Cited

1. Annual Report of the Director, Technological Laboratory, for the year ending 31 May, 1952. Published by the Indian Central Cotton Committee, Bombay (1952).
2. Balls, W. L., *A Method for Measuring Length of Cotton Hairs,* Macmillan & Co. Ltd., London (1921).
3. Chakrabarti, B. K., TEXTILE RESEARCH JOURNAL **26,** 17 (1956).
4. Turner, A. J., "Technological Reports on Standard Indian Cottons, 1923–26," *Technological Bulletin, Series* A, No. 3 (1927) or *Technological Bulletin, Series* A, No. 88 (1955).

Improved Method for Bulk Compression of Staple Fibers

INDUSTRIAL RAYON CORPORATION
High Polymer Research Division
9801 Walford Avenue
Cleveland 1, Ohio
May 11, 1956

To the Editor
TEXTILE RESEARCH JOURNAL

Dear Sir:

Bulk compression characteristics of wool fibers were studied and recently reported by deMaCarty and Dusenbury [1]. During our investigations of a similar nature on the bulk compression properties of synthetic fibers, we found an improved piston cup assembly which proved satisfactory for both synthetic and natural crimped staple fibers.

In our design, the tests were conducted by placing 50 g. of fiber, opened by a pair of cotton hand cards, in a specially designed 6-in. I.D. by 4-in. deep cup which was then closed with a cover having a 2-in. diameter hole in the center, shown in Figure 1. The cover was found necessary to keep the bulk volume of the test fiber constant. A plunger cylindrical in shape with a 1.593-in. diameter (2 sq. in.) was attached to the load cell of the Instron with the plunger centered in the opening of the covered cup which was connected with the crosshead of the tester. It should be pointed out that the diameter of the plunger is small as compared with the diameter of the cup holding the fibers. The object of this design was to avoid the "wall effect" of a close fitting piston previously reported in use. Fibers in the cup were compressed by raising the cup assembly against the plunger at a constant rate of compression (5 in./min.) up to a given load (1000 g.); then the cup was lowered at the same rate back to the original position. The pressing and the releasing of the cup against the plunger were recorded in the form of a cyclic curve (Figure 2), and the enclosed area, representing the total work loss of the cycle, was read off from the integration unit attached to the Instron. Both the per cent of compression and the work loss of the fiber were calculated from these data.

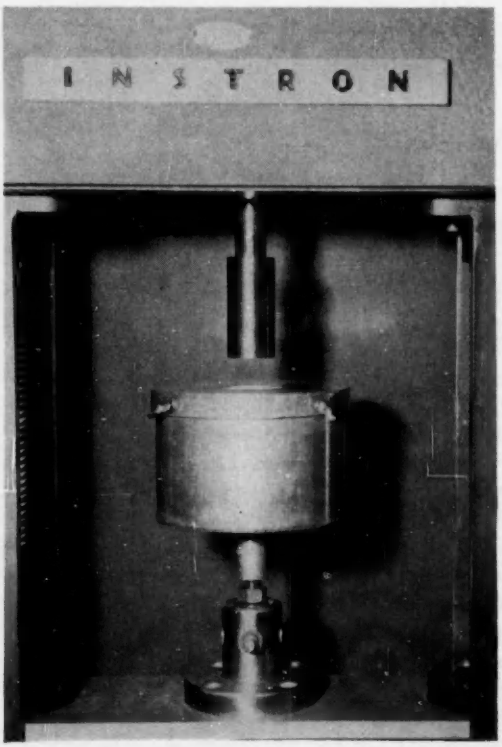


Fig. 1. Bulk compression apparatus.

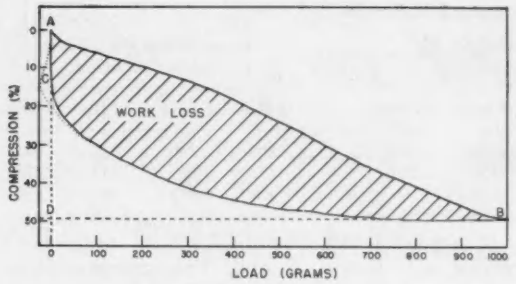


Fig. 2. Typical bulk compression curve for crimped staple fiber mass.

During the releasing portion of the cycle, the cylindrical design of the plunger eliminated the fiber drag; the fibers would pull on the piston if it were of the flat foot design similar to the one used by deMaCarty and Dusenbury [1]. With a flat foot plunger, which we formerly used, negative load (tension) was recorded near the end of the releasing cycle (dotted curve of Figure 2). This gave an erroneous result for the work loss of the fiber mass. Therefore, we prefer the cylindrical type for our present plunger design.

The covered cup also provides a means of keeping the bulk of the fiber mass in a constant volume. This is particularly important in testing a high bulk fiber. It is realized, of course, that this procedure does not necessarily assume the constancy of the fiber mass directly beneath the piston during compression; however, any lateral migration of the fiber should be less than in the case of the wall-less type apparatus.

The study of resilience was also a part of our investigation. We agree perfectly with deMaCarty and Dusenbury [1] in that resilience, when expressed in the usual energy ratio form, is not a suitable parameter for bulk fiber compression studies. It can be shown that fibers having entirely different forms of stress-strain curves and quite different "hand" can exhibit the same resilience as defined by the energy ratio equation. Complete reliance on such resilience results would lead to totally different conclusions compared with those obtained subjectively. By keeping the maximum load constant at 1000 g., we found that the per cent of compression and the work loss (energy of deformation minus energy of retraction) provided a better measure of differences among various crimped staple fibers.

By applying the above technique on various fibers, the average percentage of compression and work loss were calculated from at least five runs of each sample. Between each run, samples were uncovered and loosened by hand. It was not too difficult to obtain a consistent result this way in spite of the problem of getting a uniform packing of the fiber mass.

Table I lists some of the typical results for immediate recovery tests. Table II shows results for repeated compression (cyclic tests). Fiber samples, in

TABLE I. Immediate Recovery Test Results

Staple sample (as is, except as noted)	No. of runs	% Compression			Work loss, in.-g.		
		Max.	Min.	Av.	Max.	Min.	Av.
Dacron 5400,* S.D., 3d, 1½″	10	40.0	29.8	34.3	561	370	473
DuPont nylon Type 201, S.D. 3 d., 2½″	5	62.5	56.0	59.7	783	711	757
DuPont nylon Type 200, S.D. 3 d., 1½″	5	62.0	57.2	60.2	829	726	789
IRC nylon staple, S.D. 3 d , 1½″	10	59.0	54.5	56.6	745	630	694
Orlon 42,† 3 d., 2″	5	37.2	29.5	32.8	445	294	371
Polyacrylonitrile 3 d., 2″	5	33.5	27.0	30.2	467	288	366
Acrylic copolymer, 3 d., 3″	5	26.8	22.8	25.0	344	234	292
Carpet wool, scoured	5	43.0	38.8	41.2	532	418	480

* Du Pont polyester fiber.
† Du Pont acrylic fiber.

TABLE II. Cyclic Test Results

Sample	No. of runs	Av. % compression			Cumulative Av. Work loss (in.-g.)		
Cycle no.		I	II	III	I	I+II	I+II+III
Dacron 5400, scoured	5	23.5	23.8	24.2	308	511	686
Acrylic, copolymer, scoured	5	21.6	21.7	21.7	263	432	582

TABLE III. Delayed Recovery Test Results

Sample	No. of runs	Av. % compression with holding period of				Av. work loss (in.-g.) with holding period of			
		0 Min.	1 Min.	2 Min.	5 Min.	0 Min.	1 Min.	2 Min.	5 Min.
Dacron 5400, scoured	5	22.7	23.8	23.0	23.9	294	339	323	337
Acrylic copolymer, scoured	5	21.6	20.8	19.1	19.8	275	280	257	278
Carpet wool, scoured	5	41.2	40.3	—	—	480	563	—	—

this case, were compressed to 1000-g. load, then allowed to recover to zero load, and recompressed to 1000-g. load again. These steps were repeated for 3 cycles. The cumulative work loss at the end of each cycle was recorded. However, in analyzing this cyclic test, we realized that any error involved in the integrator reading would be greatly enlarged because of the cumulative effect. Therefore, we turned to another method of testing, *i.e.*, delayed recovery.

In the delayed recovery test, the fiber mass after being compressed to a 1000-g. load was held for varying periods up to 5 min. The average percentage of compression and work loss were computed as usual. We considered the results obtained (Table III) by this method to be more significant than the cyclical test method.

Literature Cited

1. deMaCarty, P. C., Dusenbury, J. H., TEXTILE RESEARCH JOURNAL **25**, 875 (1955).

S. M. FOK
T. G. FINZEL

INDUSTRIAL SECTION

The Relation between the Softness of Handle of Wool in the Greasy and Scoured States and Its Physical Characteristics[1]

N. F. Roberts

Wool Textile Research Laboratories, C.S.I.R.O., Sydney, Australia

Summary

Three sets of samples were submitted to panels of wool buyers for appraisal of handle, and partial regression analyses were carried out to determine the association of their grading for handle with their mean diameter, coefficient of variation (C. of V.) of diameter, number of crimps per inch, staple length, Young's modulus, yield, percentage of wax, percentage of suint, and percentage of dirt.

In a preliminary experiment the mean gradings given by 12 appraisers to 36 samples, which varied in diameter from 18 to 27 μ, were analyzed. The important characteristics were found to be mean diameter, number of crimps per inch, and, in the greasy halves of the samples, the yield. The suint was the component of yield that affected handle.

In the second experiment 66 samples varying in diameter from 16.6 to 31.6 μ were appraised by ten buyers, under more carefully controlled conditions. The gradings for handle in these appraisals appear to have been determined primarily by diameter and secondly by crimp, with staple length and C. of V. of diameter having a small influence. Neither yield nor Young's modulus were significantly associated with handle.

In the third experiment 50 samples with a range of only 2.7 μ in diameter, but a range of 10 in number of crimps per inch, and of 28% in yield were appraised by five buyers who had not been concerned in the tests previously. Once again diameter and crimp, but not yield, had statistically significant associations with softness of handle.

The results suggest that softness of handle should be used more frequently in conjunction with the visual indication given by crimp for appraising fiber diameter.

I. Introduction

Many graziers and sheep breeders put a high value on "softness of handle" when selecting sheep for breeding. However, the physical characteristics determining the softness of handle of loose wool in the greasy and scoured states and the extent to which buyers differentiate in price according to handle grading are subjects on which there is very little published information.

The only report of any consequence concerning loose wool appears to be that of a preliminary investigation in 1946 by C. M. van Wyk [4] into the part played by the three factors (1) surface friction, (2) fiber flexibility, and (3) nonwool fleece constituents. He found that (1) increasing the coefficient of friction by 30% in a sample of top and three samples of scoured wool by treatment with alcoholic potash caused a notable deterioration in handle; (2) the gradings by nine wool buyers of 12 samples of scoured and teased wool were almost unrelated to the flexibility of the fiber material as indicated by measurement of their resistance to compression, but were closely related to their diameters; and (3), that

[1] Paper presented at the International Wool Textile Research Conference, Sydney, Australia, August 24, 1955.

in a series of 14 samples chosen by three wool buyers to include examples of fine wools of harsh handle and strong wools of soft handle, the fineness had apparently been judged by crimp, for the harsh-handling fine wools were much coarser in fiber diameter and the soft-handling strong wools much finer in diameter than their crimps would on the average indicate. Although the 14 samples do not appear to have been graded for handle as a single lot, van Wyk deduced by assigning grade numbers in accordance with the descriptive terms used that the percentage of nonwool constituents and the resistance to compression influenced the handle, but to a lesser extent than diameter.

In the investigation reported here van Wyk's work has been extended by examining the dependence of handle on additional physical characteristics. Greater precision in the determination of the relative importance of these characteristics is attained by having all wools graded as one lot, irrespective of count, and by using more samples and more appraisers.

Although the investigation did not cover all types of wools, it appears that in most selections of wools, differences in diameter are likely to be the major cause of differences in handle. Consequently differences in handle can be a valuable aid in detecting differences in diameter. A second important factor in determining softness grading was found to be the number of crimps per inch, but there is some evidence that this may result from observer bias. Yield apparently influences the judgment of some appraisers, but is of little consequence to others.

II. Physical Characteristics to be Considered

A complete inquiry would include examination of the psychological factors involved in appraising softness of handle and definition of this term. The scope of the work reported here was more limited, being mainly concerned with the economic question of the relative importance of those physical characteristics which determine softness of handle as appraised by wool buyers, whatever connotation "softness of handle" may have for these people. Some ideas on the connotation seem necessary, however, for deciding what fleece characters should be measured, and for checking the reasonableness of the results.

Terms relating to the hand of fabrics have been defined by the American Society for Testing Materials [1], and as these terms are used here, the A.S.T.M. definitions are given in abbreviated form below.

Physical property	Terms to be used in describing range of corresponding component of handle
Flexibility	Pliable to stiff
Compressibility	Soft to hard
Extensibility	Stretchy to nonstretchy
Resilience	Springy to limp
Density	Compact to open
Surface contour	Rough to smooth
Surface friction	Harsh to slippery
Thermal character	Cool to warm

General use of a standard terminology would lead to much more precision in discussions of handle and allow more use to be made of handle properties. The term "soft" is restricted in the above definitions to indicate ease of compression, and the term for the characteristic contrasting with softness is "hard," but in the wool trade, it is "harsh." Wool buyers were asked to appraise softness of handle, this being a trade term, but no attempt was made to influence buyers as to what the term was to mean. In the trade, handle is used as a single omnibus term, there being no custom of making separate gradings for thermal character, surface friction, resilience, and so on, although many people in the trade are well aware that there are a number of components of handle. Consequently it is very likely that buyers' appraisals were affected to some extent by all the physical properties listed in the A.S.T.M. definitions, with the exception of extensibility, and probably there was considerable personal variation in the relative importance attached to these properties.

The process by which the various physical properties affect buyers' gradings is not quite clear, but the way in which they probably enter appraisals of handle and are related to more fundamental fiber properties will now be considered.

Flexibility. The relative flexibility of staples (and other groups of fibers), considered to comprise of roughly the same number of fibers, is probably one element in appraisal, and the flexibility of a staple will depend, of course, on the average flexibility of the individual fibers. Van Wyk considered "the pliability of single fibers is involved, probably those projecting from the surface and those forming the surface of the fiber mass." As the force to bend a single fiber is minute, it appears to the writer that a comparison of fiber pliability (flexibility) can be made only on groups of fibers. If the flexibility of

individual fibers is involved, either as individuals or components of a group, two fiber characteristics involved are the bending modulus of the fiber material, and the average value of the fourth power of the diameter. The latter quantity can be expressed in terms of the mean diameter and the coefficient of variation of diameter if one makes the approximation that the diameters of the wool fibers form a normal distribution. Using the relation that in such a distribution the mean value of the fourth power of the deviations from the mean is equal to three times the fourth power of the product of the mean diameter and the coefficient of variation [Kendall, 3], it may be readily shown that

$$\sum \frac{d_n^4}{N} = d^4(1 + 6V^2 + 3V^4)$$

where d_n is the diameter of an individual fiber in a series of N fibers whose mean value is d, and whose coefficient of variation, expressed as a fraction, is V. For the most uniform wools in this investigation, V was 0.14, and for the most nonuniform wool, V was 0.26. These values of V lead to values of $1.12d^4$, and $1.41d^4$, respectively, for the average values of the fourth powers of the diameters. This difference of about 25% in flexibility would probably be readily distinguished, so that the C. of V. of diameter can be expected to be a characteristic influencing handle, but will be only a major factor in sets of samples where the contrast in C. of V. values quoted above occurs frequently, unless the C. of V. influences some handle component other than flexibility.

Since the flexibility depends on the fourth power of mean diameter, only a very small change in mean diameter is required to produce a noticeable change in flexibility.

The crimp form, and the relative disposition of fibers in staples would affect flexibility and complicate the effect of diameter on it.

Compressibility. The compressibility of the mass of wool is probably the characteristic which would be expected to have the most direct effect on the appraisal of handle. Van Wyk, however, found only a weak association of handle grading with his measurements of the resistance to compression of equal weights of wool from various samples. The characteristics determining resistance to compression of a given mass of wool are those involved in flexibility, i.e., (1) mean diameter, (2) C. of V. of diameter, (3) elastic moduli (possibly of torsion and compression as well as bending), (4) crimp form, (5) relative disposition of fibers (especially weight of wool per unit volume), and in addition, (6) the total volume, or weight, of wool being compressed. Van Wyk found in his measurements of 310 samples that resistance to compression of equal weights of wool increased approximately linearly with increase of either the number of crimps per inch or the diameter. No explanation of these relations was given, though his theoretical treatment of simplified fiber forms shows that the variation of compressibility with diameter is much less rapid than in proportion to the fourth power, provided the mass per unit volume is constant. Measurement of mass per unit volume in wool samples under appraisal conditions is virtually impossible. It is to be expected that there will be marked differences between samples in this characteristic because of differences in the fleece density of individual sheep. However, measurements on sheep suggest there should only be only a slight association of mass per unit volume with mean fiber diameter.

Resilience. The handle of a wool would be considered better if it were not only easily compressed, but also highly resilient, i.e., a large fraction of the work of compression is recovered on release of the compressive force. Resilience can be anticipated to decrease as fiber friction increases, and to depend upon the relative disposition of fibers, including their crimp form. Possibly an increase in the number of crimps per inch may improve resilience by reducing the amount of fiber alignment and packing that occur under compression. Winson [5] found that resilience increased as staple length decreased.

Density. In loose wool the compactness of the fiber assembly probably affects judgment of handle, mainly through its influence on the characteristics discussed above.

Surface contour. Loose wool has no surface like a fabric, but the smoothness of surfaces formed by groups of fibers against the fingers when wool is compressed and rubbed between the fingers is probably a factor in handle. Mean diameter and crimp form are probably the fiber characteristics involved.

Surface friction. In greasy wool, which was the main interest in this work, the frictional characteristics of the surfaces of fibers are masked by the non-wool constituents. Consequently the percentages of wax, suint, and dirt are likely to be the characteristics determining friction.

Thermal Character. A feeling of warmth (or reduction of heat loss from the skin) is probably associated mentally with soft handling fibrous materials. The main factor controlling thermal character at the low packing densities encountered with loose wool is probably the number of fibers per unit volume. As the weight of fiber per unit volume in fleece wool probably has no marked relation to fiber diameter, the number of fibers, and hence the feeling of warmth, probably increases markedly with decrease in diameter.

Of the characteristics indicated as likely to affect handle by the above discussion, mean diameter, C. of V. of diameter, number of crimps per inch, staple length, and yield have been measured in the first two sets of samples examined. Young's modulus was measured on one set, and the amplitude of the crimp wave in another.

III. A Preliminary Experiment

A preliminary experiment was carried out to ascertain which were the main characteristics determining handle and the procedure necessary to secure satisfactory appraisals.

A set of 36 samples, each about ½ lb. in weight, was selected by a man with long experience in the trade, as showing five grades of handle within approximately the one quality range of 64's. Restriction of the quality range had been sought to prevent the effect of diameter differences swamping the effects of differences in other characteristics. The samples had been selected to be almost free of vegetable matter, as consideration of the effect of this on handle was likely to be too complicated. Table I lists the mean, range, and standard deviation of the characters measured for this set of samples. It will be seen from Table I that although the average diameter (22.5 μ) and crimp (10.4/in.) were close to those ordinarily associated with 64's wool, the range of diameters (18.0 to 27.2 μ) and crimps (6.0 to 13.3/in.) is such that the man choosing the samples had evidently gone well outside the customary limits of 64's to obtain the five grades of handle.

TABLE I. Characteristics of the Set of 36 Samples Used in the Preliminary Experiment

Character	Mean	Range		Standard deviation
		From	To	
Fiber diam., μ	22.5	18.0	27.2	2.7
C. of V. of diam., %	18.3	14.2	24.8	2.5
Staple length, cm.	8.6	5.5	12.4	1.8
Crimps/in.	10.4	6.0	13.3	1.8
Yield, %	66.2	43.3	77.6	7.8
Wax/dry clean wool, %	31.9	18.1	73.7	11
Suint/dry clean wool, %	9.5	3.2	28.8	5.5
Dirt/dry clean wool, %	10.5	1.2	34.4	8.8
Handle, greasy samples, grades	0.0	−1.88	+1.75	1.0
Handle, scoured samples, grades	0.0	−1.57	+1.43	0.79

The samples were submitted to ten other appraisers, of whom eight were wool buyers of long experience, one a junior wool buyer, and one an experienced sheep classer. They were asked to divide the samples into as many grades of softness as they considered to exist, softness being judged in the manner usual in their work. Each appraiser started by selecting a number of samples considered to differ from one another in handle, and used these as references for grading the remaining samples. Appraisal of the 36 samples was usually completed in less than half an hour.

The number of grades made varied from three, by the buyer with the most senior position in the trade, to eight, by the most junior buyer. All except the most junior buyer considered two thirds or more of the samples lay within three adjacent grades, however; so it was decided that it would be sufficiently accurate for the analysis of this preliminary experiment to regard the value of a difference of one grade as being the same for all appraisers, the extra grades made by some appraisers merely reflecting keener efforts at discrimination.

A second matter to be determined was the relative positioning of the grades of the various appraisers. It was decided to assume the average handle of the set of samples to be the same for all appraisers, and convert each appraiser's grades into deviations from his own average. For example, for the distribution: Grade 1 (2 samples), Grade 2 (14 samples), Grade 3 (12 samples), Grade 4 (6 samples), Grade 5 (2 samples), the average grading of all samples is 2.78, and relative to this origin the grade deviations are $-1.78, -0.78, +0.22, +1.22, +2.22$. The average of the grade deviations given to each sample by the eleven appraisers was then computed, and taken as the handle grade of the sample. Increasing positive values indicate increasing softness of handle above the mean, and vice versa for negative values.

There were often considerable differences among appraisers in their gradings of samples. The stand-

ard deviation of the grade deviations given to a sample was 0.81, and the average of the 11 grade deviations, taken as the handle grade, thus had a standard error of 0.24 grades.

After the samples had been appraised in the greasy state, they were divided in half, and one half of each sample was scoured in soap, soda, and water, and submitted to five of the original appraisers who were experienced in buying scoured as well as greasy wool. The samples showed a variable amount of felting, some being fairly heavily felted. The appraisers were asked to adjust for felting as far as practical, i.e., as when actually buying scoured wool. It seemed probable judgments were affected by the density of felting. To test this the samples were hand-carded and resubmitted.

The dependence of handle on the various characters listed in Table I was determined by computing in the usual way the coefficients of the partial regressions of handle on these characters [Fisher, 2].

Greasy Samples

When this was done for the handle of the greasy samples, taking yield as one of the variables, but omitting the components of the nonwool constituents that determine yield,[2] the results were as shown in Table IIA. The partial regression coefficient for a character is the change in handle grade corresponding to unit change in that character, all other characters listed being kept constant. Thus, for example, the handle deteriorated 0.17 grades for each one micron increase in fiber diameter. The accuracy with which the coefficient is determined is indicated by the ratio t of the coefficient to the standard error with which it is determined, and from this ratio the probability that the regression is due to chance (its significance level) can be ascertained from standard tables. It will be seen from the t values in Table II, and the significance levels for various t values given below the table, that the probability that the regression of diameter or yield is due to chance is only about 0.001. For crimp it is about 0.10 and for C. of V. of diameter and staple length, it is much higher than this.

Actually there is less than a 50% chance that either of the last two characters affected handle in this experiment. Table II also shows the *standard* values of the partial regression coefficients of the various characters. The standard coefficients are the ordinary partial coefficients, multiplied by the ratio of the standard deviation of the respective characters within the set of samples to the standard deviation of handle gradings within the set. The standard partial coefficients are thus indicators of the extent to which the distribution of handle gradings in the set could be caused by variations of a particular character, and of the relative importance of the characters in causing handle variations. It will be seen that the order of importance is diameter, yield, and crimp, with the latter only about half as important as the first two.

Table IIB is similar to Table IIA except that yield has been replaced by the components of the nonwool constituents and C. of V. and staple length, for which the regression coefficients were not significant in Table IIA, have been omitted. Table IIB shows that the regression of handle on the percentage of suint is significant at the 0.1% level, that the

[2] Except for the effects of variations in moisture content from its standard value, which were small in these samples, % yield = 100 − (% wax + % suint + % dirt) if wax, suint, and dirt are expressed as percentages of the greasy weight.

TABLE II (A and B). Greasy Samples in the Preliminary Experiment: Partial Regression of Handle on Various Wool Characters

	A				B*		
	Partial coeff.	Std. partial coeff.	t†		Partial coeff.	Std. partial coeff.	t
Diam.	−0.17	−0.47	3.5	Diam.	−0.16	−0.42	3.6
C. of V. of diam.	−0.028	−0.070	0.72	Crimps/in.	0.16	0.28	2.4
Staple length	−0.010	−0.018	0.2	% Wax	−0.004	−0.040	0.57
Crimps/in.	0.12	0.22	1.7	% Suint	−0.07	−0.39	3.3
% Yield	0.051	0.40	3.8	% Dirt	−0.01	−0.09	0.7

* In Table B the characters insignificant in Table A are omitted and yield is replaced by the nonwool fleece constituents.

† t = ratio of coefficient to its standard deviation. Probability that regression is due to chance is as follows: t = 1.70, 0.1: t = 2.04, 0.05: t = 2.75, 0.01: t = 3.65, 0.001.

Standard deviation of handle grading from total regression on the five characters = 0.52 in Table A, 0.46 in Table B.

percentages of wax and dirt are apparently of little importance, and it confirms the significance of the regressions on diameter and crimp. Table IIB thus leaves us with the impression that handle is determined by diameter, percentage suint, and number of crimps per inch. The question of whether the regression of handle on yield in Table IIA can be merely the reflection of the regression of handle on percentage suint in Table IIB calls for some comment, however. Since the correlation between yield and suint in this set of samples was only − 0.67 and the regression of handle on yield was slightly more significant than its regression on suint, it seems likely that wax or dirt, or both, also affected handle even though they did not attain significance in Table IIB. This Table suggests dirt was the more important.

Possible reasons for the dependence of handle on crimp and diameter have been discussed in the preceding section. Suint, being very hygroscopic, may have made the wool sticky to the touch and thus impaired its handle. Individual dirt particles are mainly smaller than wool fibers in diameter, so that only the larger particles, or conglomerates, would be expected to give a rough or gritty handle to the wool. The number of larger dirt particles is probably highly correlated with the percentage dirt present and in this way percentage dirt may affect handle.

The regressions of Tables II A and II B each account for about 80% of the total sum of squares of handle gradings, and for either table the standard deviation of handle gradings from the over-all regression on the five characters considered was about 0.5 grades.[3] As the standard error or appraisal of handling grading was about 0.24 grades it seems that most, but perhaps not all factors determining handle have been considered.

TABLE III. Uncarded Scoured Samples in the Preliminary Experiment: Partial Regression of Handle on Various Wool Characters

	Partial coeff.	Std. partial coeff.	t
Diam.	−0.17	−0.57	3.88
C. of V.	−0.00	—	—
Staple length	0.10	0.23	2.23
Crimps/in.	0.12	0.27	1.8

The significance of the "t" values is as for Table II.

Standard deviation of handle grading from regression on the five characters = 0.48 grades.

[3] I.e., the sum of squares due to regressions was approximately 80% of the total sum of squares, and the square root of the mean of the squares about regression was approximately 0.5 grades.

Scoured Samples

When the dependence of the handle of the scoured, uncarded samples, was analyzed by the partial regression technique, omitting yield and nonwool constituents from the factors considered, the results shown in Table III were obtained. The regression on diameter and crimp is much the same as for the greasy samples, and the C. of V. of diameter remains insignificant, but staple length has moved from a position of insignificance for greasy samples to a low level of significance in the scoured samples. Handle was found to improve as the staple length increased, which is the opposite to what would be expected from Winson's results [5] for the effect of staple length on resilience. Possibly the improvement of handle with staple length may result from a decrease of felting with increase in staple length.

When the samples were carded and reappraised, the coefficient of ordinary (i.e., not partial) correlation between handle and diameter increased from − 0.76 to − 0.87, and the ordinary coefficient of regression on diameter from -0.22 ± 0.03 to -0.29 ± 0.03. This strongly suggests that the handle of the uncarded samples was influenced by the degree of felting. As the hand-carded samples did not constitute either a commercial product or experimental material with well-known characteristics (e.g., crimp form), analyses of the hand-carded samples was not carried out in detail.

Owing to the limitations of this preliminary experiment further examination of the data of greasy or scoured samples seemed less likely to yield accurate information than a better experiment and this was accordingly undertaken.

IV. Main Experiment

A second experiment was undertaken in which a number of improvements were made in the light of the first experiment.

Two appraisers, whom the previous experiment had shown to be close to average in their gradings, selected a series of 65 samples, each of about 1 lb. weight, which they considered showed a range of five grades with approximately equal numbers in all grades, and differed no more from 64's quality than was necessary to get five distinct grades of handle.

The measured characteristics of the set are listed in Table IV. As in the first set, the range of 15 μ

TABLE IV. Characteristics of the Set of 65 Samples Used in Second Experiment

Character	Mean	Range		Standard deviation
		From	To	
Fiber diam., μ	22.9	16.6	31.6	3.8
C. of V. diam., %	18.8	14.0	25.5	2.7
Staple length, cm.	8.1	6.1	11.8	1.5
Crimps/in.	11.6	5.8	17.2	3.2
Young's modulus, 10^{10} dynes/cm.^{2}	2.57	1.66	3.48	0.41
Yield, %	64.8	47.3	77.9	6.7
Wax/dry clean wool, %	30.0	11.5	80.5	12
Suint/dry clean wool, %	7.0	2.1	16.3	3.4
Dirt/dry clean wool, %	19.0	4.7	56.1	10
Handle, greasy samples, grades	0.0	−2	+2	1.3
Handle, scoured samples, grades	0.0	−2	+2	1.3

in diameter (16.6 μ to 31.6 μ), and 13.7 crimps/in. (5.8 crimps/in. to 19.5 crimps/in.) shows that the selectors had gone well away from 64's quality to obtain the extremes of handle. Five of the harshest handling samplings were actually Downs-type wools with diameters of over 28 μ. The range and standard deviations of fiber diameters is greater in the second set than in the first. However, the ratios of the standard deviation of diameter to the standard deviation of handle scores is 2.69 and 2.88 for greasy samples in the first and second experiments, respectively, and 3.4 and 3.0, respectively, for scoured samples; so that grade intervals did not necessarily correspond to larger diameter differences in the second experiment.

In an endeavor to determine the extent to which variations in handle were caused by variations in elastic properties, the Young's modulus of samples in this set was measured. Although the bending and torsion moduli are mainly involved in appraising handle, the Young's modulus is much easier to measure, and on general grounds it appeared highly probable that there should be close correlation between the three moduli. A Cambridge extensometer was used at an extension rate of 1 cm./min. Eight fibers, in pairs from four different staples, were measured for each sample. The average coefficient of variation of Young's modulus in a sample was found to be 13.5%, so that the standard error in the mean of the eight fibers was 4.8%. As the coefficient of variation among the means of the 65 individual samples was 15.8%, any marked effect of Young's modulus on handle would have probably shown itself.

Instead of attempting to simulate commercially scoured wool, as in the first experiment, it was decided to clean the wool with the minimum possible disturbance of staple formation, with the hope that the difference between the handle gradings of the greasy and cleaned samples would elucidate the effect of nonwool constituents. Half of each sample was cleaned by soaking and gentle squeezing in warm carbon tetrachloride and two warm water rinses.

The greasy and cleaned samples were displayed in an air-conditioned room maintained at 70° F. and 65% R.H. Each evening for five days two experienced buyers graded the samples, taking about 1½ hr. for the 130 samples. Five of the buyers had participated in the preliminary experiment.

All appraisers were asked to divide the samples into five grades, if possible, so that grade intervals would have much the same value for all appraisers. Actually the buyer occupying the most senior position in the trade again distinguished less grades than the others—four in the greasy samples, and three in the cleaned samples. One other appraiser distinguished only four grades in the cleaned samples. To start with, each appraiser was given 15 samples, made up of three of each grade, as assessed by earlier appraisers, and asked to select from these, as standards, five samples he considered to represent different grades of handle. The remaining 50 samples were then passed to him for grading, and he afterwards went over the samples in each of his grades to see whether any adjustments should be made.

Using the same method as in the preliminary experiment, each appraiser's gradings were converted into deviations from his own mean grading, and the average deviation allotted by all ten appraisers then computed and used as the grading of the sample. When appraisers had made only three or four grades, their deviations were multiplied by an appropriate factor, as it seems clear in this experiment that intervals between such grades corresponded to larger differences than when five grades were made. Differences between gradings by different appraisers were much less in the second experiment than in the first, the average standard deviation among gradings of a greasy sample being 0.47, and the standard error of the mean grading by the ten appraisers, therefore, 0.15. The corresponding figures in the first experiment were 0.81 and 0.24, respectively. For gradings of scoured handle in the second experiment, the figures were 0.49 and 0.16.

Greasy Samples

When a partial regression analysis was carried out, using the first six variables in Table IV, i.e., including yield, but not the nonwool constituents, the results shown in Table V were obtained. This table is to be compared with Table IIA, the variables being the same except for the addition of Young's modulus. Disposing of this character first, it can be noted that Young's modulus was apparently of little importance in causing variations of handle. Its coefficient has the right sign, i.e., negative, indicating that an increase in Young's modulus causes a deterioration in handle, but its standard partial coefficient is inconsiderable, and the t value does not indicate that the regression is likely to be anything but a chance result. This will be examined in more detail later.

The other features of the comparison between Table IIA and Table V are (1) that the important regression on yield in Table IIA has disappeared in Table V, where there is only a very small coefficient for yield, and only a 50% chance of it having had any effect at all, (2) that the values of the coefficients for the other four characters common to the two tables agree within the value of the standard error with which the coefficients were determined in the analysis of Table II, and (3) that the t values of the regression on all these four characters are much higher in Table V than in Table II. Those for C. of V. and staple length have become significant at about the 10% level, that for diameter so high that the close dependence of handle on diameter can be regarded as a certainty. The regression on the variables in the analysis accounts for nearly all (93%) of the total sum of squares of the handle gradings.

TABLE V. Greasy Samples in the Main Experiment: Partial Regression of Handle on Various Wool Characters

	Partial coeff.	Std. partial coeff.	t
Diam.	−0.22	−0.64	9.3
C. of V.	−0.042	−0.087	1.8
Staple length	−0.056	−0.064	1.5
Crimps/in.	0.12	0.29	3.4
Young's modulus	−0.10	−0.035	0.86
Yield	0.007	0.061	0.63

Probability of a regression being due to a chance is indicated by t value as follows: $t = 1.67$, 0.1: $t = 2.00$, 0.05: $t = 2.66$, 0.01: $t = 3.46$, 0.001.

Standard deviation of handle grading from regression on the 6 characters = 0.38.

It will be seen in Table V that the standard partial coefficients of diameter (0.64) and crimp (0.29) are much higher than the coefficients of any other characters, and as crimp and diameter are highly correlated in this set of samples ($r = -0.764$), it follows that crimp and diameter have almost completely determined the handle gradings. The coefficient of ordinary correlation of handle grading with diameter was 0.92, and of handle with crimp 0.87.

An analysis in which yield was replaced by the nonwool constituents was carried out, but just as the regression on yield was insignificant in this experiment, so were the regressions on suint, wax, and dirt. Reference to Tables I and IV shows that the second set of samples had a lower average suint content (7.0% in comparison with 9.5%), and a smaller range of suint contents than the first set. This may have been part of the cause, but does not appear likely to have been the sole cause for the contrast between the two experiments in regard to the importance of suint and yield.

Cleaned Samples

Table VI shows the result of a partial regression analysis, using the same variables as Table V. The values of the partial regression coefficients agree, within the accuracy of their determination, with those in Table V. As yield had no effect on the gradings of the greasy samples, the original object of appraising the cleaned samples, *viz.* the elucidation of the role of the nonwool constituents, is not attained. The analysis offers useful confirmation of the results of Table V, however. Young's modulus remained an insignificant factor, and the sign of its coefficient was opposite for the scoured samples from its sign for the greasy samples, further reducing the likelihood that it is of any importance. There is

TABLE VI. Cleaned Samples in the Main Experiment: Partial Regression of Handle on Various Wool Characters

	Partial coeff.	Std. partial coeff.	t
Diam.	−0.25	−0.73	11
C. of V.	−0.060	−0.13	2.9
Staple length	−0.078	−0.092	2.2
Crimps/in.	0.075	0.19	2.3
Young's modulus	0.12	0.038	0.82
Yield	0.019	0.10	2.4

The significance of t values is the same as for Table V.

Standard deviation of handle grading from regression = 0.34.

some doubt that the accuracy with which Young's modulus was determined was sufficient. However, there were six cases in which a sample had a Young's modulus which was less by at least one third than that of samples having the same diameter, and in none of these cases was there much indication that the modulus had affected the handle. Either Young's modulus is not closely correlated with the bending and torsion moduli involved in handle appraisal, therefore, or elastic moduli play a very minor role in handle appraisal.

One interesting change from Table V is that yield, though still having a very low coefficient in Table VI, is indicated by its t value as probably having a real association with the handle of scoured samples. It seems that this should be regarded as a close association due to chance. A certain number of such associations must be expected, of course, when a large number of regressions are calculated.

V. A Third Experiment

The analyses of the preliminary and main experiments both reveal a regression on diameter of about -0.2 handle grades per micron, and a low probability—in fact, in the second experiment, a negligible probability—that this regression is due to chance. Both experiments also reveal a regression on crimp of about 0.1 handle grades per crimp per inch, but the possibility of it being due to chance is not quite negligible. This, together with the lack of an obvious physical reason why the handle should improve as the number of crimps per inch increases, suggests that further confirmation of this regression is desirable. In regard to the importance of yield and suint, the two experiments gave contradictory results, so further investigation of this point seems necessary also.

It was possible to test these points conveniently by a third series of 50 samples on which measurements of diameter, crimp, and yield were available. The set was characterized by having only a very restricted range of diameter (2.6 μ), but a large range and standard deviation of crimp and yield, having been specially selected from five different strains of sheep. The characteristics of the set are summarized in Table VII.

TABLE VII. Characteristics of the Set of 50 Samples Used in the Third Experiment

Character	Mean	Range		Standard deviation
		From	To	
Diameter, μ	22.5	21.4	24.0	0.79
Crimps/in.	10.9	7.4	17.5	3.7
Yield, %	67.3	47.5	75.6	9.8
Handle, grades	0	−0.9	+1.4	0.73

As there was some possibility that the appraisers in the main experiment, though making their gradings most conscientiously, may have been subconsciously affected by discussions among themselves of the characteristics affecting handle, five buyers not previously concerned with any tests were invited to appraise the samples, and no discussion of handle characteristics was entered into prior to the appraisals. First some samples from each of the five grades of the main experiment were presented, these were appraised into five grades, and samples from the third set were then graded, using the samples of the main set as references. Three of the buyers considered the samples of the third set extended over four of the grades of the main experiment, and two of the buyers considered the third set extended over only three of the grades.

The mean of the gradings given to each sample was calculated in the same way as in previous experiments, but a difference of one grade was assumed to have the same value, whether made by an appraiser who considered three grades existed, or by one who considered four grades existed, since both had used samples from the main experiment as grade standards.

The results of the partial regression analysis are given in Table VIII. They reveal that the dependence of handle on crimp in these buyers' gradings is beyond reasonable doubt. Even though differences in diameter were so small in this set of samples, a definite regression of handle on diameter was again shown, the value of the partial coefficient being much the same as in previous analyses. The regression on yield attained only a modest level of signifi-

TABLE VIII. Greasy Sample in the Third Experiment; Partial Regression of Handle on Various Wool Characters

	Partial coeff.	Std. partial coeff.	t
Diam.	−0.25	−0.27	3.3
Crimps/in.	0.24	0.89	7.5
Yield	0.022	0.20	1.6

The significance of t values is approximately the same as for Table V.

Standard deviation from regression = 0.41.

cance, and the value of its regression coefficient was intermediate in value between that obtained in the preliminary and main experiments. Possibly the interpretation of these results is that yield affects the gradings of some appraisers considerably, but others only to a slight extent. An inspection of gradings by individual appraisers suggests that those occupying the more important positions in the trade were somewhat less dependent on yield than others.

The coefficient of the regression of handle on crimp in the third experiment was about twice that in the previous two experiments. This difference is sufficiently large to be of some interest, even though the coefficients in the three experiments are not strictly comparable. (Some minor characteristics were omitted from analyses in the third experiment, for example.) The explanation is possibly as follows. Buyers mentally associate various *average* degrees of softness with various numbers of crimps per inch, and they appraised samples conforming to these average characteristics (the samples from the main experiment given to them as references) just before the third experiment. The slow crimping wools of the latter experiment were therefore visually classed into the lowest grade for handle, until touched. They were then upgraded because they were finer than is usual for their crimp. However, it can be anticipated that this upgrading will be nonlinear, the ratio of the increment in handle grading to diameter deviation not being as large for large deviations in diameter as for small deviations. The slow crimping wools thus did not receive as high gradings as they should have received. Similarly the fast crimping wools, which were much coarser than is usual for their crimp, did not receive as low gradings as they should have received. The gradings of the set were thus extended beyond their proper range by the appearance of their crimp. That appraisers may be influenced by appearance seems evident from the fact that a number of appraisers, including one in this experiment, stated they could tell how a wool would handle before they touched it. All concerned in this experiment were most surprised when told, after they had appraised the samples, that those with 16 crimps per inch were of almost the same diameter as those with 8 crimps per inch. That appraisers are usually nonlinear in gradings has been shown in a number of experiments; for example, in estimating the yield of wools, very high-yielding wools are usually underestimated and very low-yielding wools overestimated.

VI. The Use of Handle Appraisal in Wool Buying

The results collected in the experiments described in earlier sections can be analyzed to predict fleece characteristics from handle gradings. If the *partial* regression of diameter on handle, keeping crimp constant, is calculated for the greasy samples in the main experiment, the regression coefficient is $-3.0\ \mu$ per handle grade, i.e., superiority by one grade to other wools of the same crimp indicates a diameter smaller by $3\ \mu$. The *ordinary* regression of diameter on handle has a coefficient of $-2.7\ \mu$ per grade, i.e., allowing all characters, including diameter to vary with handle in their average fashion, the change of diameter with handle grade is $-2.7\ \mu$ per grade. This is smaller than the *partial* regression coefficient of -3.0 because usually some of the change in handle is due to variation of other characters besides diameter. For the scoured samples in the main experiment, the ordinary coefficient is -2.8. For the preliminary experiment it is -2.1 for the greasy samples and -2.6 for the scoured samples. There is a good measure of agreement, therefore, that in a collection of samples showing an appreciable range in all characters, (such as the sets in the preliminary and main experiments), a difference of one handle grade corresponds on the average to a difference of about $2.5\ \mu$ in diameter, and further, that if characteristics other than diameter that affect handle (principally crimp and yield) are kept constant, a difference of one grade in handle corresponds, on the average, to a difference of $3\ \mu$ in diameter. As the handle gradings used in the above experiment were not easily detected by all appraisers, a definite difference in handle probably corresponds to a diameter difference larger than $3\ \mu$. These results should be of assistance to buyers whose clients have specified the fineness of the wools to be purchased, since it became evident during the tests that there were larger diameter differences in most collections of wools than most buyers realized.

Actually most English and Australian manufacturers do not specify the fineness of the wools they require. They specify count which is defined not in terms of fiber characteristics, but only by samples, and is, in practice, determined for most buyers primarily by crimp, and to a lesser extent by handle. All 20 buyers who cooperated in these tests were asked how handle affected their valuation of wool, and nearly all replied that it did so only if it affected

their estimate of its count, since this was the only characteristic related to handle usually specified by their clients. The majority of buyers depressed their estimation of the count of a wool by one step if the handle was unusually harsh for the number of crimps per inch, i.e., a harsh wool with a 64's crimp would be valued as a 60's. A much smaller number of buyers also adopted the reverse procedure, for example, a wool with a 64's crimp and unusually soft handle would be valued as a 70's.[4] In view of the investigations reported here it would seem that this practice could be adopted more widely. A wool distinctly softer than another of the same crimp will, on the average, be finer than it by at least 3 μ, i.e., it will have the diameter which is average for wools two or more counts finer. If the soft wool, therefore, is valued as if it were one count higher than its crimp indicates, it will still be finer by the equivalent of one count than the average of the group in which it is placed, and such limited information as is available on the roles of crimp and diameter in manufacture suggests that superiority in fineness by the equivalent of one count will amply compensate for inferiority in crimp of this amount for most types of cloth.

The frequent occurrence of considerable discrepancies between the gradings given by individual appraisers and the mean grading of all appraisers is a limitation to the widespread use of handle gradings in the immediate future. These discrepancies probably derive to a considerable extent from the lack of an agreed definition of handle based on recognition of the various components of handle. This is a practical problem which can probably be remedied. Colleges teaching wool classing could assist, for example. Greater precision in the appraisal of fineness could probably be attained if the dependence of the various handle components on fiber characteristics were evaluated separately. The investigations reported here have not shown whether the major role played by diameter in present gradings is due to the influence of diameter on fiber flexibility, weight of wool per unit volume, thermal character, or some other component.

The process by which crimp contributes to handle also needs clarification. To the writer's fingers the contribution of the number of crimps per inch to handle is different from that of fiber fineness; increasing the number of crimps per inch seems to give the staples more dimensional stability and resilience. In addition to the number of crimps per inch, the depth of the crimp wave, or its shape, i.e., the ratio of its amplitude to its wave length would have some influence. In an endeavor to evaluate their importance these characteristics were measured on the samples in the preliminary experiment. It was found that when the analyses of Table II were extended to include crimps per inch, amplitude per wave length, and depth of crimp, the regression on crimp depth just exceeded the 5% level, and the regressions on the other crimp parameters were quite insignificant. This suggests that depth of crimp may be the important characteristic rather than number of crimps per inch. The two characteristics were highly correlated ($r = 0.81$), indicating the shape does not usually vary much as the number of crimps per inch is varied.

It is hoped to investigate some of these matters more fully and also the widely held opinion that the type of country on which wool is grown affects its handle.

[4] Buyers of wools finer than 70's make more use of handle in assessing count than do buyers of wools coarser than 70's.

Acknowledgments

It is a pleasure to acknowledge the assistance of Miss H. N. Turner, who supervised the analysis of the first experiment, of Dr. H. A. David who supervised the analysis of the second, and Miss Betty Halliburton who did much of the computing, including investigation of many points that space precluded from discussion in this paper.

Literature Cited

1. American Society of Testing Materials, *Supplement to Book of A.S.T.M. Standards,* Part 7, A.S.T.M. Philadelphia, p. 41 (1954).
2. Fisher, R. A., *Statistical Methods for Research Workers,* Oliver and Boyd, London, pp. 156–166 (1950).
3. Kendall, M. G., *The Advanced Theory of Statistics,* Vol. 1, Griffin & Co., London, p. 54 (1947).
4. Van Wyk, C. M., "A Study of the Compressibility of Wool, with Special Reference to South African Merino Wool," *Onderstepoort J. Vet. Sci. Animal Ind.* **21**, 100–226 (1946).
5. Winson, C. G., "Report on a Method for Measuring the Resilience of Wool," *J. Text. Inst.* **23**, T386–393 (1932).

Manuscript received March 2, 1956.

Spindle Drafting of Woolen Slubbings

J. Angus[1] and J. G. Martindale[2]

Abstract

An apparatus incorporating a single mule spindle was designed to draft woolen slubbings under a variety of conditions of twist and speed, and to measure the drafting forces generated. Experiments were done on this apparatus and on the mule itself.

The way in which drafting force is generated was investigated for Cheviot and Saxony slubbings with varying speed, count, and twist. The way in which the thread irregularity changed during drafting was investigated simultaneously. It was found that force first increased with extension and then decreased. During this second stage of decreasing force, evidence was sometimes found of the spasmodic slipping and sticking of fibers. Levelness of thread improved while drafting force was increasing, but deteriorated rapidly as the force declined. This indicates that optimum draft might be determined by force measurements. The angle of inclination of the spindle was also found to affect the magnitude of the drafting force.

A two-phase hypothesis of fiber behavior has been advanced, in which it is suggested that fiber response during the first phase consists mainly of straightening and stretching. This is superseded by a second phase which is characterized by fiber slippage, often of a violent nature.

It is suggested not only that this does provide a new standpoint from which the process of spindle drafting can be considered, but also that development of the experimental technique might provide ready means of investigating the importance of various fiber properties, and their modification, in the spinning process.

I. Introduction

In a previous paper, Angus and Martindale[3] described an instrument for the continuous recording of the forces generated in the thread at all points during the cycle of spinning operations on the woolen mule. Simultaneously it recorded the movement of the carriage and the number of turns which had been made by the spindle since the beginning of the cycle. These latter are the independent variables determined by mechanical settings of the machine, which govern the tension developed in the thread at any particular instant. It was therefore possible to trace the manner in which thread tension depended at all stages throughout the cycle, upon any practical combination of mechanically set conditions.

Although it was possible to study conditions during all parts of the cycle, and although tension fluctuations during the phases of backing off and winding on must be of great importance in yarn making, interest was focussed on the drafting phase because it must be here that the chief characteristics are imparted which govern the quality of the resultant yarn. In particular, being provided with a given carded slubbing, if conditions during backing off and winding on are set to handle the thread gently, then it is during the drafting that the important characteristics of yarn levelness are determined. Levelness is the prime requisite of most woolen yarns; it determines the acceptability of the appearance of woven and knitted fabric made from it, and is the determining factor in governing the efficiency with which the yarn will process. On the mule the special interest in this aspect of levelness is that an irregular thread will not spin so well, there will be many ends down which will reduce the efficiency of the operation.

When this work commenced, there was no means of measuring the changes in levelness of a thread while it was being produced and even now the possibilities of doing this are very limited. It was therefore hoped that a study of the tension fluctuations in the thread[4] during drafting would be rewarding, as it might give some guidance to the accompanying

[1] Yarrow Wool Spinners Ltd., Yarrow Mill, Selkirk; formerly Scottish Woollen Technical College, Galashiels.

[2] Scottish Woollen Technical College, Galashiels.

[3] Angus, J., and Martindale, J. G., *J. Text. Inst.* **43**, T565, (1952).

[4] The use of the term thread will be reserved for the material in the process of being drawn, to distinguish it from its original condition—slubbing—and its final condition—yarn.

changes in thickness along the length of thread being drafted—what we might call its "weight profile"—and suggest some suitable means whereby optimum drafting conditions for the production of the most uniform yarn could be recognized, and in particular cases, determined by trial runs prior to the processing of a batch. It was felt also, looking a long way ahead, that work of this kind might eventually lead to recognition of fiber properties which are conducive to good spinning characteristics, thus enabling investigations into such things as the effect of scouring and dyeing procedures, or the addition of oils or other assistants, to be made. The factors in these processes which are favorable or detrimental to good spinning efficiency and the production of a level yarn, might thus be elucidated.

All this has not been achieved, but significant relationships have been found between the fluctuations in the force acting upon the drafting thread and the changes which take place in levelness during drafting. This has enabled tentative suggestions to be made regarding the behavior of fibers subjected to this type of drafting. In addition new light is thrown on the question of optimum conditions necessary to produce the most uniform yarn.

In the previous paper Angus and Martindale [3] show that as drafting proceeded on the mule, the force generated in the thread increased. Sometimes, depending upon the relative rates of twist insertion and application of draft, this force reached a maximum value and began to decline before drafting was completed, while in other cases the drafting force was still increasing when the carriage reached the outward end of its run. Measurements of the irregularity of the yarns showed that this also changed by measurable amounts as the drafting conditions were altered, although it appeared that the response of different wools to these varying conditions might vary somewhat. There were good grounds therefore for proceeding with the investigation of drafting force characteristics, the way in which they were governed by the method of setting and running the mule, and the way in which these characteristics were related to the levelness of the yarn produced.

For systematic investigation of spindle drafting under a variety of conditions, however, the mule presents difficulties. First, it must be clothed with large quantities of material, whereas for the elucidation of principles one needs only to make investigations on a single end. Second, it is a cumbrous machine to operate and small changes in spinning conditions are not made easily or quickly. Third, the rate of carriage movement, i.e., drafting, is not uniform, being determined by the revolution of a scroll of gradually diminishing diameter. Therefore, even though the spindle inserts twist at a uniform rate during drafting, the turns per inch (t.p.i.) in the thread are also changing continuously, and changing at a variable rate, throughout the drafting period. It was concluded, therefore, that the complexity of the drafting conditions imposed by these factors precluded any but the most empirical of approaches to the investigation on the mule itself, and that if a better appreciation of the process was to be obtained it was necessary to make a new apparatus. This should handle a single end, and enable spindle drafting to be carried out in such a way that carriage speed and rate of revolution of the spindle could both be governed independently, simply, and in a manner to be prescribed as required. Initially it was decided to provide for a variety of constant carriage speeds, and a variety of constant spindle speeds which would enable t.p.i. in the thread to be kept constant during drafting.

The present paper describes the experiments carried out on this apparatus and discusses their possible significance. It also describes some experiments carried out on a mule to confirm that the experimental apparatus gives results which are valid on the mule itself.

II. Experiments with a Single-Spindle Apparatus

a. The Apparatus

The equipment consisted of a fixed tension recording apparatus mounted on a bench, and a moving carriage carrying a rotating spindle which ran along the bench away from the tension recorder. Both were of simple construction.

The tension recorder was similar to that described previously by Angus and Martindale.[3] It consisted of a light aluminum lever mounted in a vertical position and pivoting in ball bearings. At its lower end was fitted a clamp, which gripped one end of the tensioned test slubbing, and its deflection under a given force was determined by restraining springs; thus the sensitivity could be altered by using springs of different stiffness. The system was damped by an attached vane which moved in an oil bath. The deflection of this spring-loaded lever under the influence of the tension in the slubbing under test was

recorded by a pen on a paper chart. The paper was carried on a drum which was rotated directly from the moving carriage by a chain and gear drive. Thus, as the carriage receded, it rotated the recording drum and the pen was displaced in a direction parallel to the drum axis, and so traced out a force-elongation curve for the test slubbing in rectangular coordinates.

The carriage consisted of a simple framework fitted with four rubber-tired wheels. On this was mounted a fairly heavy motor of ample power. A simple system of spur gears geared the motor shaft to the driving pair of wheels, and change wheels enabled six different carriage speeds to be used. Another set of spur gears, driven from the final carriage wheel drive, rotated a spindle mounted on the carriage; suitable change wheels permitted any one of seven different ratios of spindle speed to carriage speed to be selected for any carriage speed. Table I shows the six carriage speeds and the seven rates of twist insertion, any combination of these two values being available.

The relatively heavy weight of motor and carriage, together with the rubber-tired wheels and a motor of ample power, ensured that the carriage accelerated to its final speed very rapidly without slipping, and similarly, when the motor was switched off the carriage stopped almost instantaneously.

The spindle, which was an exact replica of the top half of a Whiteley woolen mule spindle, was fixed at the normal angle, slightly forward of the vertical. Alternatively, it could be lowered into a horizontal position for drafting, in which case a small clamp was fitted to the spindle tip to secure the end of the slubbing. No breaks at the spindle tip, or at the jaws of the clamp of the tension recorder, were noted during drafting with the spindle mounted in either position.

In woolen spinning a very common drafting procedure is to deliver a 48-in. length of slubbing and draw it to 72 in. (draft = 1.5). It was therefore decided to experiment with initial lengths of 48 in. of slubbing. The carriage was then set with its spindle tip 48 in. distant from the nip of the clamp of the tension recorder. A length of slubbing somewhat longer than this was carefully unwound from a condenser bobbin, one end was gripped and the other end placed in the clamp of a twist tester, and twist of the required amount inserted in the slubbing before submitting it to test. For example, if it was required to study the drafting of a slubbing at a constant value of 3.00 t.p.i., then the slubbing had 3.0 t.p.i. inserted into it before placing it in the single-spindle apparatus; the gearing necessary to give 3 t.p.i. carriage movement was then selected, and on extending the slubbing during test, 3 turns would be inserted for every inch of elongation, thus maintaining the initial twist content. On the other hand, if it was desired to examine drafting during conditions of increasing twist content (a condition simulating more closely the actual case of mule spinning), one could prepare a slubbing with, say, 2.0 t.p.i., and select spindle gearing which would insert, say 6.25 t.p.i. of carriage movement. Under these conditions the twist content of the slubbing would be increased during drafting—during drafting from 48 to 72 in., the twist content would be increased from 2.0 to 3.4 t.p.i.

TABLE I. Speeds and Twists Available on Single-Spindle Apparatus

Carriage speed (in./min.)	Spindle t.p.i. of carriage movement
48	2.20
71	3.00
92	3.75
108	4.85
159	6.25
209	8.05
	10.65

The effect of the inclination of the spindle will be mentioned in describing the results obtained, and a remark on this is therefore appropriate at this point. With the spindle inclined in the normal near-vertical position, the test slubbing was secured at this end by wrapping a few turns round the spindle and leading it up to the spindle tip in a spiral; the other end was drawn through the recorder clamp, which was secured when the merest indication of tension in the slubbing was indicated by the recorder. For a horizontal spindle the slubbing had to be clamped to it, and secured in a similar way at the recorder, with that instrument showing a slight tension.

When the normal near-vertical spindle position was employed, the effect of which every mule spinner is aware and which we call "spindle-plucking," was noted when the spindle rotated. For rather more than half a turn of the spindle the thread wraps round the spindle tip in a spiral form. It then passes over the nose and the coil is thrown off. This repeated winding on and throwing off once per spindle

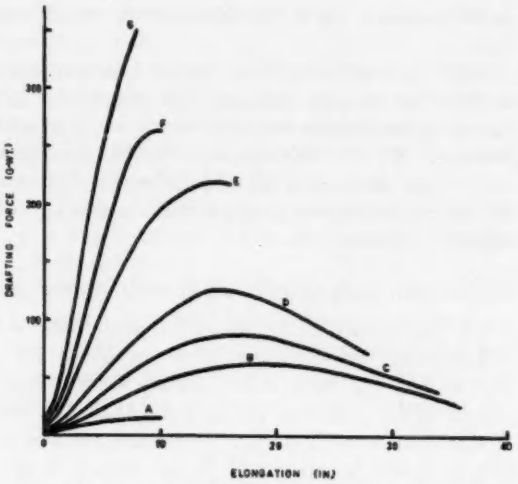


Fig. 1. Force-elongation curves for Cheviot slubbings with different twist contents. Spindle horizontal. Initial test length 48 in.

A, 0.0 t.p.i.; *B*, 2.2 t.p.i.; *C*, 3.0 t.p.i.; *D*, 3.75 t.p.i.; *E*, 4.85 t.p.i.; *F*, 6.25 t.p.i.; *G*, 8.05 t.p.i.

revolution causes a plucking of the thread which could be seen as a ripple on the force-elongation curve obtained. This ripple was absent on the records obtained as a result of a "straight draw" with a horizontal spindle. As will be mentioned, this high speed plucking action seems to make a distinct contribution to the normal drafting action of a mule spindle.

b. Drafting Force at Constant Speed of Drafting

Figure 1 summarizes the results of a series of tests in which a Cheviot slubbing (54's quality) weighing 12 g./100 m. was drafted at a constant speed of 92 in./min. The initial length of slubbing was 48 in. The spindle was in the horizontal position. Each curve shown represents the average behavior of 10 threads.

In each case the force developed as elongation proceeded and a region of approximate linearity was reached. It then rose less rapidly and, for the lower values of twist content, reached a maximum, and then fell off gradually until breakage occurred. As the twist content of the material was raised, the progression of curves showed an earlier appearance of this maximum. The point of breakage also occurred at an earlier value of elongation, until, at the highest twist content, breakage occurred so early that no maximum was reached. These higher values of twist content during drafting are never approached in practical spinning; with such a high twist content the thread is in fact more like a yarn, and gives a curve similar to the normal load-elongation curves for yarns.

Similar results, recording the average behavior of a Saxony slubbing (64's quality) weighing 9.4 g./100 m., are shown in Figures 2 and 3. Figure 2 shows the results with the spindle in the horizontal drafting position, and Figure 3 the results when the spindle was erected in the normal near-vertical position. Both sets of curves show the same general features as Figure 1. The values of drafting forces were smaller, as might be expected with a lighter slubbing, and a noticeable feature was that the

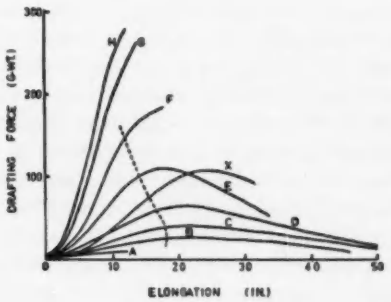


Fig. 2. Force-elongation curves for Saxony slubbings with different twist contents. Spindle horizontal. Initial test length 48 in.

A, 0.0 t.p.i.; *B*, 2.2 t.p.i.; *C*, 3.0 t.p.i.; *D*, 3.75 t.p.i.; *E*, 4.85 t.p.i.; *F*, 6.25 t.p.i.; *G*, 8.05 t.p.i.; *H*, 10.65 t.p.i.; *X*, twist increasing from original 3.0 t.p.i.

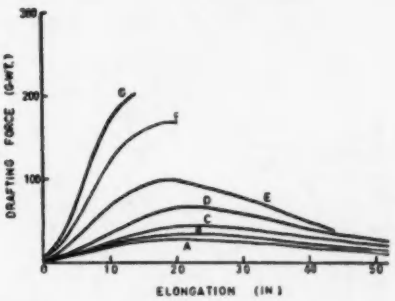


Fig. 3. Force-elongation curves for Saxony slubbings with different twist contents. Spindle near vertical. Initial test length 48 in.

A, 2.2. t.p.i.; *B*, 3.0 t.p.i.; *C*, 3.75 t.p.i.; *D*, 4.85 t.p.i.; *E*, 6.25 t.p.i.; *F*, 8.05 t.p.i.; *G*, 10.65 t.p.i.

maxima occurred later in drafting; some 4 or 5 in. greater elongation was achieved with the Saxony material before the maximum force was recorded. Similarly the elongation at breakage was greater.

A feature of particular interest in the results for Saxony was the difference resulting from the positioning of the spindle. When the spindle was in the near-vertical position, this plucking action produced an oscillating drafting force, which showed in individual records as a ripple. In the curves of Figure 3, each being the average of 10 individual records, this ripple was smoothed out, but it will be remarked that this oscillation appeared to have three effects: (i) with the inclined spindle the drafting force was, in every case, lower than the corresponding force at the same elongation for straight drafting, (ii) the appearance of maximum force seemed to occur at a greater value of elongation, and (iii) a much greater amount of drafting was achieved before breakage occurred. This was perhaps most marked in the thread which was drafted with 6.25 t.p.i., where almost 40-in. elongation at break was achieved with the inclined spindle, whereas only about 18 in. was possible with the horizontal spindle and the maximum of the force elongation was scarcely reached.

It has already been mentioned that records of this kind can also be obtained with the apparatus under conditions of increasing twist content during drafting. In Figure 2, curve *X* shows the results of one such test among a number that were made.

It was thought that it might be of interest to investigate the reaction of a worsted roving to spindle drafting under similar conditions. Accordingly 48-in. lengths of Botany roving (64's quality, 4 drams/40 yd.) were drawn at constant speed, maintaining a twist content of 3.0 t.p.i. Figure 4 shows the mean force-elongation curve for the average of 12 such tests.

It will be seen that this curve has a similar shape to those for woolen slubbings, the noteworthy difference being that the maximum force was generated after only 2.7 in. of elongation. Further consideration of the similarities of, and differences between, the curves for woolen and worsted materials is reserved for Section IV.

c. The Effect of Speed of Drafting on Drafting Force

The dependence of the tensile properties of yarns and worsted-type slivers upon rate of elongation is well known, and these results merely extend observations of this kind into the field of spindle drafting. It was considered important to investigate this effect, as it will be necessary, in due course, to take into account the effect of machine speeds and their variation, in any interpretation of drafting behavior on the mule itself.

The results of a series of tests at the six speeds available are shown in Figure 5. A constant twist content of 3 t.p.i. was used in each case, each curve again representing the average behavior of 10 threads. The initial length of each slubbing drafted was again 48 in. The records for speeds of 92 in./min. and 108 in./min. were so closely similar that they have been represented by one curve.

The form of each curve was almost identical, except that the extent of drafting was curtailed at the higher speeds. It is worth noting that a fourfold increase in speed produced a 40% increase in force, and that the magnitude of this effect was propor-

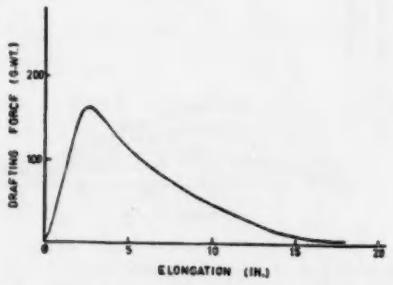


Fig. 4. Force-elongation curve for spindle drafting of worsted roving. Initial test length 48 in. Twist content 3.0 t.p.i.

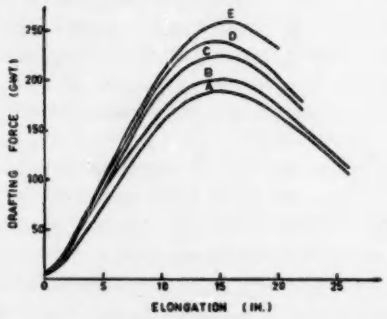


Fig. 5. Effect of speed of drafting on force-elongation curves for Cheviot slubbing. Initial test length 48 in. Twist content 3.0 t.p.i.

A, 48 in./min.; *B*, 71 in./min.; *C*, 92–108 in./min.; *D*, 159 in./min.; *E*, 209 in./min.

tionally much less than the effect of a similar increase in twist content.

Similar records were obtained with different twist contents for both spindle positions. These indicated that the effect of speed became less noticeable as the twist content was increased, and also that the speed dependence for inclined spindle drafting was greater than in straight drafting, presumably due to the superimposing of more repeated plucking operations in the former case.

The uniformity of the shape of these curves over a range of speeds may be taken to indicate that the behavior of fibers is not altered in character, but that the magnitude of the force is governed by the time available to fibers to respond to the influences applied.

d. The Effect of Variations in Slubbing Weight on Drafting Force

In the tests which have already been described, 10 or more individual slubbings were drafted under each set of test conditions, and although the shapes of the individual force-elongation curves were substantially the same, the force developed at a given elongation in the different specimens varied in magnitude. The effect of the inevitable differences in the weights of 48-in. specimens on drafting force was therefore investigated.

In order to obtain sufficient observations to work out the correlation, the results for slubbing tested under different conditions were combined as follows.

The weight and maximum drafting force was obtained for each individual test length. The average weight of the slubbings used for each spinning condition was calculated, and also the average maximum drafting force for that condition. The values for weight and force for the individuals were then divided by their respective averages, and a correlation was sought between these pairs of quotients. It was clear at this point that the relationship between them was relatively insensitive to differences in the spinning condition.

A typical set of some 150 results obtained from the Saxony material is shown in Figure 6. The correlation coefficient between force and weight was 0.78, and the slope of the regression line for force against weight was 2.26. Thus a change in weight of 1% produced a change in force of just over 2%. Values between 0.7 and 0.8 for the correlation coefficient, and between 1.9 and 2.3 for the slope of the regression line, were obtained for the other slubbings investigated.

In view of the great irregularity along the length of individual slubbings such a high correlation between its total weight and the drafting force is rather surprising. One might think that the maximum force would be determined largely by the properties of a particular element of the thread, which might not be very closely related to the count of the specimen as a whole (i.e., the weights of the remaining sections might appear at first sight to be unimportant). It is possible, however, that the fairly close correlation is accounted for by the interplay between weight and twist along the thread.

A similar calculation was made for the 4 dram, 3 t.p.i. worsted roving investigated, and a similar degree of correlation ($r = 0.83$) was found between weight and force. However, the slope of the regression line was very much greater, being approximately 10. Thus a 1% change of weight in a worsted roving produced a change of 10% in drafting force, and the variation between individual force-elongation records was much greater than that for woolen slubbings. This effect must be related to the more regular and parallel array of fibers in worsted roving.

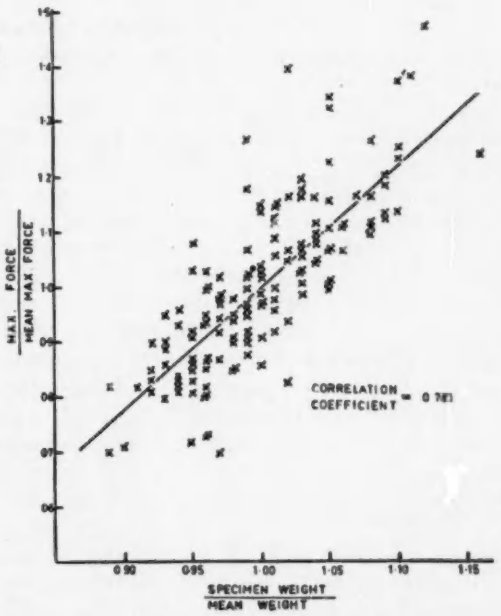


Fig. 6. Effect of variation in weight of slubbing specimen on maximum drafting force for Saxony slubbing.

e. Irregularity of Drafted Thread

Results already described show how drafting force develops. The experiments described in this and the next subsection show how the irregularity of the thread changes as drafting proceeds.

For the measurement of irregularity an electronic levelness tester of the capacitance type was built and used. The test condenser had a length of 1 in. Calibration of the instrument had shown that the correlation between instrument reading and the weight of a 1-in. specimen was of the order of 0.98.

The first tests were made on the same Saxony material as was used to obtain the force-elongation curves (Figures 2 and 3). Drafting was carried out with various constant twist contents, the procedure being as follows. Measurements of thickness were made for each inch of a 40-in. length of slubbing and the coefficient of variation of wt./in. was calculated. The slubbing was next twisted, until it had the twist appropriate to the drafting condition required, and its irregularity was measured again *before drafting.* It was then placed in the single-spindle apparatus and drafted. Different specimens were drafted to different extents, 5 being drafted by 6 in., another 5 by 12 in., another 5 by 18 in., etc. Each specimen was removed after drafting, and its irregularity was again measured.

Table II shows the complete set of results for this Saxony material, drafted with 3.0 t.p.i. constant twist content, and the spindle in the horizontal position. The ratio of the coefficient of variation of the thread to that of the initial piece of slubbing was defined as a "smoothing coefficient." Table II indicates the degree of consistency in the results obtained, and the last row of figures shows that as drafting proceeded the smoothing coefficient first decreased and then began to increase, i.e., the thread first became more uniform and then became rapidly worse. It is also to be noted that the mere act of twisting without drawing produced a small decrease in thread irregularity.

For this Saxony material with the spindle in the horizontal position, a complete set of experiments was carried out for constant twist contents of 2.20, 3.0, 4.85, and 6.25 t.p.i. Figure 7 summarizes the results in graphical form, smoothing coefficients being plotted against draft.

With the higher twist contents the full draft of 36 in. could not be applied, as many or all of the threads

TABLE II. Change of Irregularity with Draft

Saxony slubbing of initial length 48 in. with 3.0 t.p.i. twist content. Spindle horizontal.

	Elongation (in.)						
Draft:	0 1.00	6 1.125	12 1.25	18 1.375	24 1.50	30 1.625	36 1.75
C.V. of slubbings, %							
(i)	15.2	12.8	14.6	14.0	14.3	14.1	13.6
(ii)	13.4	14.3	15.0	16.5	13.7	14.2	11.9
(iii)	11.8	11.6	14.4	17.0	17.5	17.0	11.7
(iv)	14.4	18.1	16.3	16.2	15.9	13.7	13.1
(v)	11.3	13.1	15.6	15.8	15.0	12.5	15.6
Mean	13.2	14.0	15.2	15.9	15.3	14.3	13.2
C.V. of thread after drafting, %							
(i)	14.2	11.4	14.2	10.0	10.8	12.0	21.7
(ii)	13.2	13.9	12.5	12.0	10.5	12.7	16.8
(iii)	11.8	10.8	12.6	14.6	14.2	19.9	25.0
(iv)	14.4	16.3	12.6	13.2	14.7	16.1	20.2
(v)	11.0	12.3	11.7	12.3	12.2	12.0	21.4
Mean	12.9	12.9	12.7	12.4	12.5	14.5	21.0
Smoothing coefficient*							
(i)	0.93	0.89	0.97	0.72	0.76	0.85	1.60
(ii)	0.99	0.97	0.80	0.73	0.77	0.90	1.42
(iii)	1.00	0.93	0.88	0.86	0.81	1.17	2.13
(iv)	1.00	0.91	0.77	0.82	0.93	1.18	1.54
(v)	0.97	0.94	0.75	0.78	0.81	0.96	1.37
Mean	0.98	0.93	0.83	0.78	0.82	1.01	1.61

* Smoothing coefficient = (C.V. of thread)/(C.V. of slubbing).

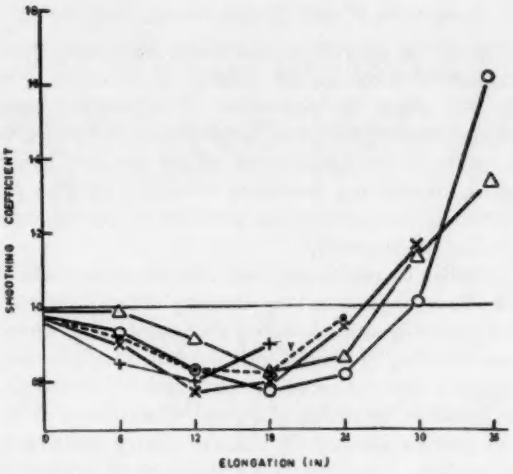


Fig. 7. Effect of draft on thread irregularity. Saxony wool with different twist contents. Spindle horizontal. Initial test length, 48 in.

△ 2.2 t.p.i.; ○ 3.0 t.p.i.; × 4.85 t.p.i.; + 6.25 t.p.i.; ● twist increasing from 3.0.

broke before this draft could be achieved. However, the general characteristics of the curves are similar. Drafting produced a steady fall in smoothing coefficient, i.e., in irregularity of thread, until a minimum value was reached at a certain optimum draft. For drafts beyond this a rapid increase in thread irregularity followed. It was then noticed that as twist content increased, this point of optimum draft occurred at correspondingly lower values. This was reminiscent of the results obtained on the force-elongation curves, where the elongation for maximum force also decreased as twist content was increased (Figures 2 and 3). The values of optimum draft cannot be specified very accurately from Figure 7; they may not be very critical, but they were estimated and transferred to Figure 2, a broken line being drawn through their estimated positions on the force-elongation curves. It will be seen that this line intersects the various force-elongation curves at, or near to, their points of inflexion, a finding which is discussed later.

Curve *X* (Figure 2) showed the force-elongation relationship in one case of twist increasing during drafting. Irregularity measurements were therefore made on material drafted similarly, and the broken line *Y* (Figure 7) gives the results of this test. The initial twist content was 3.0 t.p.i., and extra twist was inserted during drafting at the rate of 10.65 t.p.i. of carriage movement.

Again it is to be seen that the optimum draft on curve *Y* occurs at a value corresponding approximately to the point of inflexion of the force-elongation curve *X* (Figure 2). Thus this experimental finding appears to be valid in cases of drafting against increasing twist, as well as in the case of drafting against constant twist.

There is a definite indication in Figure 7, that the higher twist contents produced a progressive improvement in the regularity of the slubbing *before* draft was applied. If this improvement results from contraction produced by twisting, as twist is not inserted uniformly but concentrates in the thinner sections, then the thinner places may contract more than the thick places and so become proportionally heavier. This would explain the reduction in irregularity of weight per unit length, and also the increase in this effect with increasing twist content.

There is also some slight suggestion in Figure 7 that the improvement in regularity at optimum draft is greater at the higher twist contents. This would have to be confirmed by further observations. In any case, practical considerations suggest that the effect, if present, may not be very important, because the range of twists which can be used in drafting on the mule is less than in these experiments.

Figure 8 shows a similar set of experimental results obtained with a Cheviot slubbing with the spindle in the near-vertical position. This was a different wool from that used when obtaining the force-elongation patterns for Cheviot threads, and therefore is not directly comparable with Figure 1. These results confirm the main pattern of behavior shown by the Saxony, and also indicate that the inclination of the spindle does not affect it qualitatively.

In connection with this test on Cheviot wool, it should be stated that it was not found possible to handle the untwisted slubbing safely in the levelness tester without risking damage to it. It was not possible, therefore, to measure slubbing irregularity at zero twist. The slubbing was first twisted to the condition required in the test to be made on it, and in this case the values of smoothing coefficient plotted are the values of the ratio of thread irregularity to that of *twisted* slubbing. For this reason all these values are 1.0 at zero draft. However, it was found that as initial twist increased, measured irregularity of the undrafted slubbing decreased, as in the case of the Saxony material.

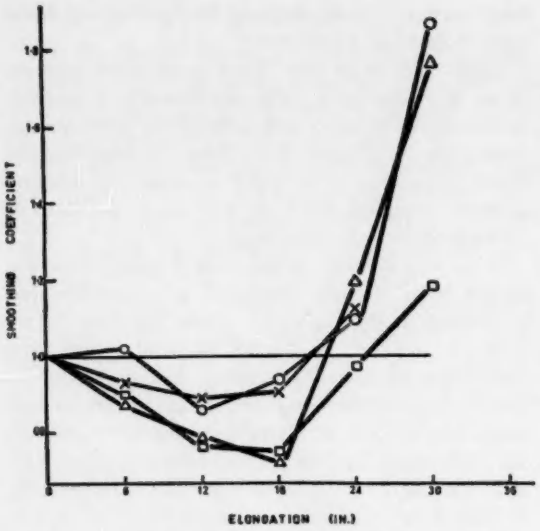


Fig. 8. Effect of draft on thread irregularity. Cheviot wool with different twist contents. Spindle near vertical. Initial test length 48 in.

△ 2.2 t.p.i.; ○ 3.0 t.p.i.; □ 3.75 t.p.i.; × 4.85 t.p.i.

Irregularity tests had therefore been made on a Saxony slubbing drafted with a horizontal spindle at a variety of twist conditions, and on a Cheviot slubbing under similarly varied twist conditions, but drafted with a spindle in the normal near-vertical position. To make a more complete comparison some further tests were therefore done at 3.0 t.p.i. constant twist content with the Saxony, using the near-vertical spindle, and with the Cheviot, using the horizontal position.

Figure 9 shows the results, which bring out clearly the effect of wool quality and spindle position. The immediately obvious points are that in all cases the behavior was qualitatively the same, that the near-vertical spindle—presumably because of its plucking action—allowed a greater draft to be applied to either slubbing without detriment to thread irregularity, and that the Saxony thread was capable of being drafted further than the Cheviot before the same degree of irregularity was produced. The latter observation is parallel to those made on the force-elongation curves for Saxony and Cheviot, viz., that the maximum forces were generated at greater values of elongation for Saxony slubbing.

f. Changes in Weight-Profile during Drafting

With the capacitance levelness tester, spot readings were taken of the weight of successive 1-in. lengths along the slubbings. The readings were plotted consecutively in a horizontal direction to give a record of the variation of weight per unit length along the slubbing, known as its weight profile. No recording instrument was available to record these profiles automatically.

Similar measurements, and records, were made of the threads produced by drafting these slubbings; the longer length of record obtained from a thread was reduced by simple scaling (scale factor = draft applied) to correspond to the length of record obtained from its parent slubbing. Comparison of the two profiles allowed the behavior during drafting to be studied. The tests were all made on 48-in. lengths of slubbing drafted in the single spindle apparatus.

As each record had its own individuality, it is possible to present only one or two examples to illustrate the general behavior noted. Results obtained upon the insertion of twist, but with no applied draft, are shown in Figure 10. These two pairs of records show virtually no alteration in profile. The improvement in the coefficient of variation in each case resulted from minor changes in the weight of exces-

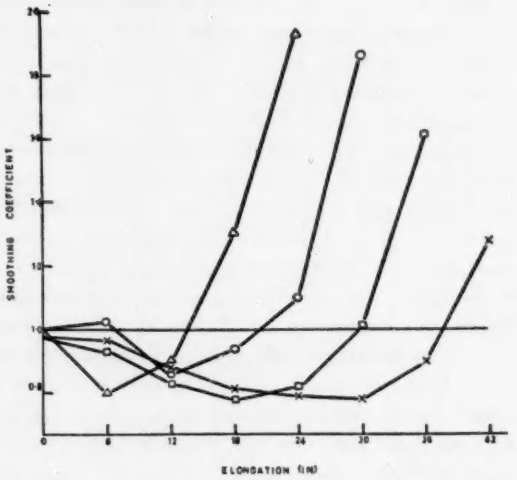


Fig. 9. Effect of spindle position on irregularity/draft relation. Twist content 3.0 t.p.i. Initial test length 48 in.

△ Cheviot wool, spindle horizontal.
○ Cheviot wool, spindle near vertical.
□ Saxony wool, spindle horizontal.
× Saxony wool, spindle near vertical.

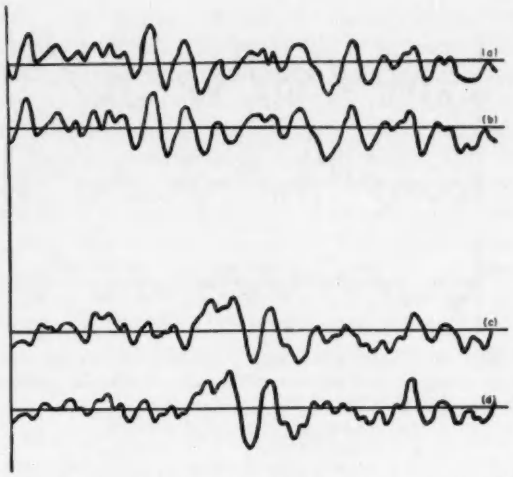


Fig. 10. Weight profiles of Saxony slubbings before and after twisting.

(*a*) Initial slubbing, untwisted. C.V. = 11.8%.
(*b*) Twisted slubbing, 3.00 t.p.i. C.V. = 11.4%.
(*c*) Initial slubbing, untwisted. C.V. = 14.9%.
(*d*) Twisted slubbing, 4.85 t.p.i. C.V. = 13.6%.

sively thick, or excessively thin, places combined with a tendency toward a smoothing of the running mean of the profile, i.e., a reduction of long-term trends.

The profiles in Figure 11 show the results of drafts of (*a*) 12 in. (25%), (*b*) 18 in. (37%) and (*c*) 30 in. (62.5%), applied to three different Saxony slubbings. In the first of these (Fig. 11*a*) there was still a marked similarity in profile after drafting, although the reduction of extreme deviations and the smoothing of the running mean resulted in a substantial decrease in the coefficient of variation. A similar state of affairs is seen in Figure 11*b*, although a few discrepancies between individual sections were now beginning to appear. These became increasingly obvious at higher drafts, and in Figure 11*c* the two profiles bear much less resemblance to one another. In particular, two very thin sections had appeared. They appear in this instance to have developed from thick places in the slubbing. Improvement in coefficient of variation had now been superseded by a deterioration. Many observations of a similar nature on various types of slubbings confirmed the general behavior illustrated by these examples, but the information obtained was limited by the "before and after" technique employed.

The profile changes were next followed in successive stages by submitting a slubbing to a series of small drafts and measuring the profile after each. It must be remembered that this is not representative of normal drafting, since two disturbing factors are introduced by this treatment. In the first place, the thread is subjected to repeated slight disturbances by removal, testing, and replacement. Secondly, the material has a chance to relax during the intervals between drafting. From deductions made during the work, it is thought that the second of these factors is the more important, and that it may confer on the thread an ability to draft further than it would have done had the total draft been applied in one operation.

Figures 12 and 13 show weight profiles obtained from the progressive drafting of Cheviot-type slub-

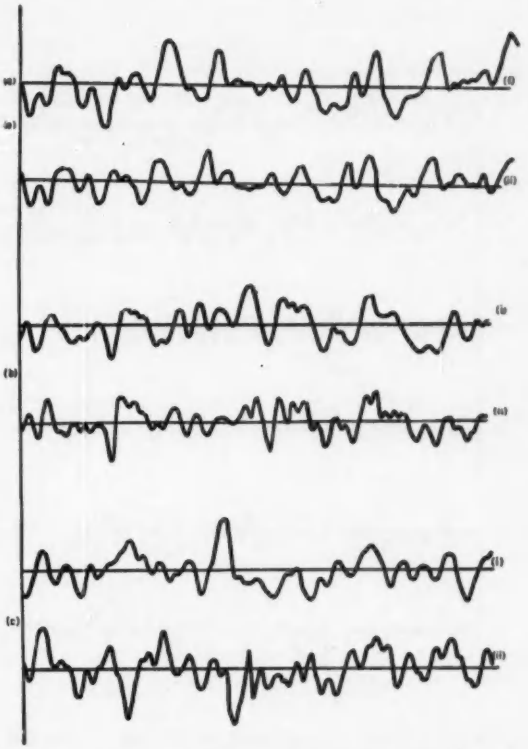


Fig. 11. Weight profiles of Saxony slubbings before and after drafting. Twist content 3.00 t.p.i.

(*a*) (i) Initial slubbing. C.V. = 15.6%.
(ii) Thread drafted 25%. C.V. = 11.7%.
(*b*) (i) Initial slubbing. C.V. = 16.2%.
(ii) Thread drafted 37.5%. C.V. = 13.2%.
(*c*) (i) Initial slubbing. C.V. = 13.7%.
(ii) Thread drafted 62.5%. C.V. = 16.1%.

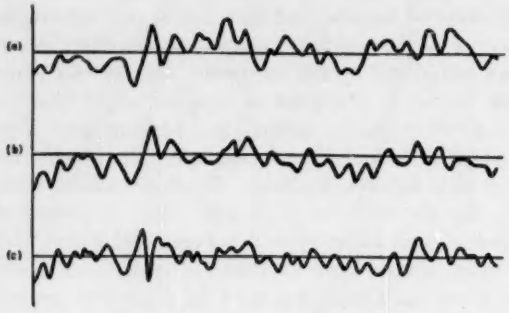


Fig. 12. Progressive stages in drafting of Cheviot slubbing showing improvement of weight profile for limited drafts. Initial length 48 in.

(*a*) Slubbing. C.V. = 13.6%.
(*b*) Draft = 1.125. C.V. = 10.5%.
(*c*) Draft = 1.25. C.V. = 9.0%.

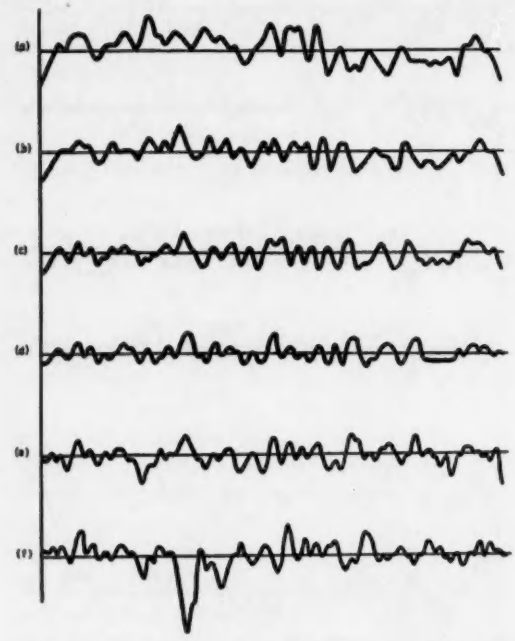


Fig. 13. Progressive stages in drafting of Cheviot slubbing. Initial length 48 in.

(*a*) Slubbing. C.V. = 10.1%.
(*b*) Draft = 1.125. C.V. = 7.8%.
(*c*) Draft = 1.25. C.V. = 7.5%.
(*d*) Draft = 1.375. C.V. = 7.2%.
(*e*) Draft = 1.5. C.V. = 9.2%.
(*f*) Draft = 1.625. C.V. = 16.5%.

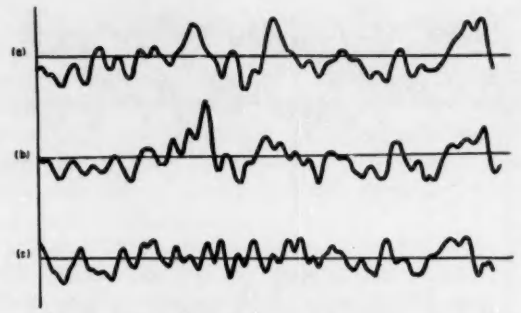


Fig. 14. Progressive stages in drafting of Saxony slubbing showing improvement of weight profile for limited drafts. Initial length 48 in.

(*a*) Slubbing. C.V. = 12.0%.
(*b*) Draft = 1.25. C.V. = 11.8%.
(*c*) Draft = 1.50. C.V. = 11.0%.

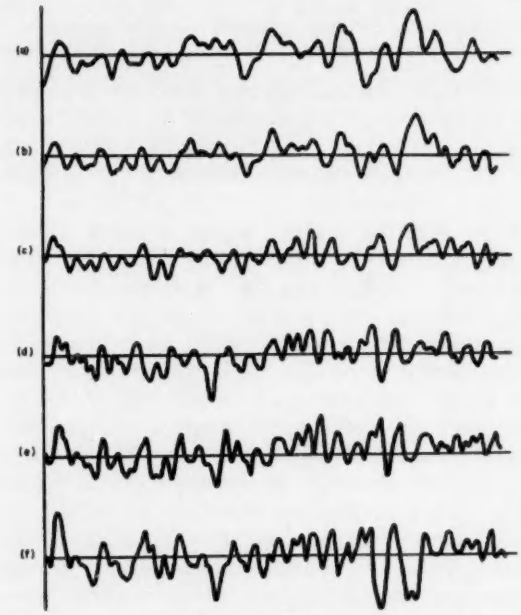


Fig. 15. Progressive stages in drafting of Saxony slubbing. Initial length 48 in.

(*a*) Slubbing. C.V. = 13.5%.
(*b*) Draft = 1.25. C.V. = 10.9%.
(*c*) Draft = 1.50. C.V. = 12.1%.
(*d*) Draft = 1.625. C.V. = 13.5%.
(*e*) Draft = 1.75. C.V. = 15.6%.
(*f*) Draft = 1.875. C.V. = 16.7%.

bings, and Figures 14 and 15 similar results from Saxony material. Figures 12 and 14 represent cases where deterioration of levelness had not yet set in because optimum draft had not been exceeded, while Figures 13 and 15 illustrate the complete behavior.

These records demonstrate the appreciable smoothing of irregularities in the early stages of drafting, particularly by the removal of the longer waves, and confirm the deterioration in the later stages previously noted in the statistical approach. In both Figures 13 and 15 excessively thin places have developed in the last drafting stage. In Figure 13 the thin place appears to have developed from a section which had previously been a thick place, and the same might be said of one of the two thin places in Figure 15. It should be remarked that this indicates preferential drafting at some places, which means nonuniform drafting along the specimen length. It therefore follows that a process of contracting the records by a scale factor equal to the average draft, although it is the best that can be done, means that an exact registering of the series of curves, one on top of the other, is not strictly admissible. Consequently one cannot draw exact deductions regarding the detailed behavior of sections by comparing points directly above or below one another. So, although the thin place of Figure 13 does appear to have originated in a section which was previously thick, the same cannot be said of the two thinnest places shown in Figure 15. They apparently developed in a section of the thread which had always been irregular, and it is as likely—from this evidence—that they sprang from its thin parts as that they came from the thick parts.

g. Fluctuations in Drafting Force and Their Relation to Changes in Weight Profile

It is reasonable to expect that large and sudden changes in the weight profile might be apparent in some form in the force-elongation curve obtained during the drafting of the specimen. A study of individual force-elongation curves for a number of slubbings showed *some* cases where an irregular decline in force occurred after the maximum had been reached. In no case were any such fluctuations found on the ascending part of the curve. Figure 16 shows three records illustrating various degrees of fluctuation of the force. Record (*c*) shows the most violent fluctuations, and it will be noted that it led to the early breakage of the thread.

With some blends this effect was so small as to be negligible. For example, it was absent from records of two Saxony blends examined; one of these was a 64's quality, the other a 70's quality. It was insignificant in a Cheviot-type blend containing New Zealand lambswool (66⅔%) and super ½ bred slipe (33⅓%), but it occurred in two blends containing waste. The first was a blend of 56/58's quality New Zealand lambswool (50%) and 60's quality pulled Botany waste (50%), and the second a wool dyed blend containing crossbred slipe wool (66⅔%) and garnetted crossbred waste (33⅓%). Figure 16 shows records from this latter blend. There is an indication therefore that coarseness of wool, mixtures of types and, possibly, dyeing processes play a part in giving rise to this effect. It was also found that the effect was more marked when the lower twist contents were used during drafting.

The effect having been noted, close observation was made while experimental drafting was carried out on further samples. Watch was kept on the force-elongation chart; when one of these marked "slip-stick" fluctuations occurred, drafting was stopped and the thread removed to have its weight profile recorded. It was found that a marked rela-

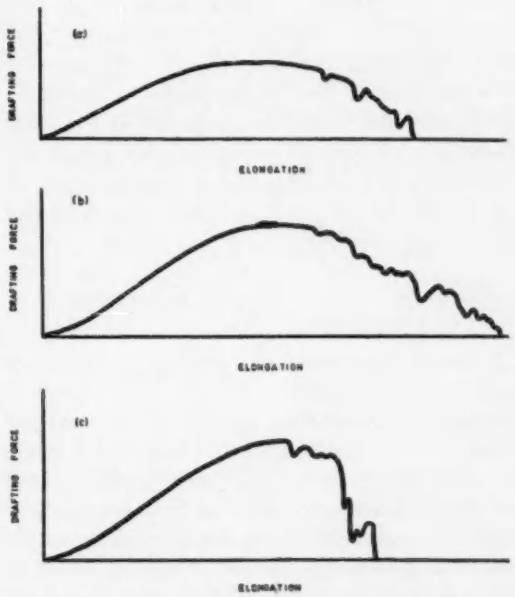


Fig .16. Three force-elongation records for individual Cheviot slubbings which show slip-stick effects when force is declining.

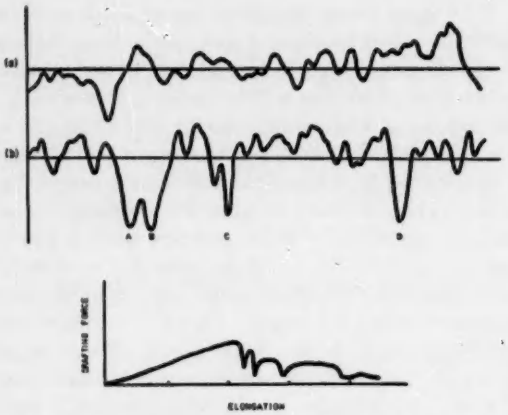


Fig. 17. Weight profile of a Cheviot slubbing before and after drafting together with the corresponding drafting force-elongation record. The four thin places which have each given rise to a rapid fall in drafting force are clearly defined. (*a*) Initial slubbing. (*b*) Drafted thread. (*c*) Force-elongation.

tionship existed between the two records, a drop and recovery in force always announcing the formation of a particularly thin place. Where the force pattern showed one, two, or more rapid falls and recoveries, the weight profile showed an equal number of excessively thin places. In some cases it was even possible, by observation of the thread during spinning, to notice the thin places being formed—because there was a violent twist redistribution at the time—and identify them with the successive violent force fluctuations. Figure 17 shows one such pair of records, four excessively thin places (marked *A, B, C,* and *D*) having developed, and four violent fluctuations having occurred.

h. Effect of Previous Treatments on Drafting Force Characteristics

It seems obvious that the physical properties of the fibers being drafted must have an all-important part to play in determining the forces developed during drafting. It is also well known that some wet processes given to wool prior to carding and spinning have a marked effect on its processing efficiency. It was therefore felt that the techniques developed in these experiments, if applied to wools treated in such a way, might give some idea of the fiber properties which are most important in determining the efficiency of the drafting operation.

Such an investigation would be a large one. The results given in this section are simply those of a first preliminary investigation to open the field.

A batch of super Geelong lambswool was being investigated by the Scottish Branch Laboratory of the Wool Industries Research Association. Half of it was scoured with trichloroethylene, and the remainder with soap and soda in a normal three-bowl scouring set. Half of each scoured lot was processed undyed, and the other half of each was dyed black by the after-chrome process. The Research Association provided lengths of slubbing after each lot had been carded, and a series of force-extension curves were obtained. Figure 18 shows the mean curves for each of the four lots—solvent-scoured white, solvent-scoured dyed black, soap-scoured white, and soap-scoured dyed black—48-in. lengths of slubbing being drawn at 92 in./min. with a constant twist content of 2.20 t.p.i. A set of curves obtained with a twist content of 4.85 t.p.i. had the same relative characteristics, the chief differences being that higher forces were developed and breakage occurred at somewhat shorter elongations.

In both cases the force recorded for the solvent

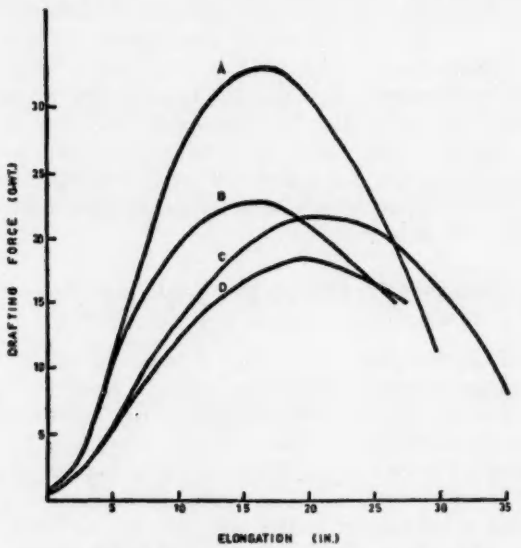


Fig. 18. Force-elongation curves for slubbings of lambswool treated in various ways before carding. Initial test length 48 in. Twist content 2.20 t.p.i.

A Solvent scoured with trichlorethylene.
B As *A* and dyed black.
C Scoured with soap and soda.
D As *C* and dyed black.

extracted wool was greater than that for the soap-scoured material at corresponding points during drafting. Dyeing also reduced the force developed. The development of the peak force occurred earlier in drafting with the solvent-scoured material, and the dyeing treatment appeared to have advanced it slightly. For the higher twist content (4.85 t.p.i.—not illustrated) elongation at break was much greater for the soap-scoured wool (25 in. as against 17 in.).

These results indicate that the elastic properties of the threads differed, as shown by the different slopes of the early part of the curves. They are all consistent with the view that the solvent-extracted material was more coherent than the soap-scoured, in that higher peak forces were developed and, particularly at 4.85 t.p.i., it broke at much smaller elongations.

These differences in the behavior of the threads are presumably related to the differences in surface properties of the fibers (friction), and in their elastic properties (stiffness). This method of investigating the importance of such fiber properties in spindle drafting therefore seems to be encouraging, and it has the advantage that the test conditions are almost identical with those under which fibers are being spun commercially.

III. Experiments on the Mule

a. Apparatus

For the recording of forces generated in threads being drafted on the mule, the apparatus described previously by Angus and Martindale [3] was used. Measurements of thread irregularity were made with the same capacitance-type levelness tester used in the experiments described in Section II.

b. Brief Review of Earlier Results

Reference is made to the results presented in Figures 8 and 9 of Angus and Martindale. These graphs showed the way in which force is generated as the mule carriage drafts the thread. The force was plotted against a time scale, but as the carriage movement is a simple function of time, these graphs are very similar to force-elongation curves. Elongation was, however, limited in all cases by the maximum permissible extent of carriage movement (72 in.).

Figure 9 (Angus and Martindale [3]) showed a family of curves obtained when a series of slubbings of initial length 48 in. were drawn to 72 in. with various average twist contents. Because of the method of twist insertion on the mule, twist was increasing continually throughout drafting, but it can be seen that the curves are of a similar shape to those obtained on the single-spindle apparatus (Figures 1, 2, and 3 of this paper) and that the forces generated also increased in a similar manner with increasing average twist content. In these experiments on the mule, however, the force did not reach a maximum and begin to decline until an elongation of 24 in. (50% extension) had been applied. This is a point of difference between these results and those obtained on the single-spindle apparatus, where force had always reached its maximum and begun to decline before this degree of draft had been applied.

Figure 8 (Angus and Martindale [3]) showed similar force-elongation curves obtained on the mule with different applied drafts. With a fixed maximum carriage movement of 72 in., the only way of varying the draft was to vary the initial length of slubbing delivered. These lengths were as follows, values of draft being given in brackets: 54 in. (1.33); 50 in. (1.44); 48 in. (1.50); 45 in. (1.60); and 40 in. (1.80).

With the two smallest drafts no maximum was reached before drafting was complete, with a draft of 1.50 it seemed that the maximum had just been reached, and with the two highest drafts a decline in force had already set in before drafting was completed. This again suggests that on the mule itself drafting can be taken further before a decline sets in, but it does appear that the general force-elongation characteristics on the mule itself are similar to those obtained on the single-spindle apparatus.

On the declining part of the force pattern for the highest draft (1.80) fluctuations in force were apparent. This suggested that slip-stick effects were also occurring. Further tests made to investigate this showed that such effects do occur on the mule, but not when the drafting force is increasing.

c. Drawing and Spinning

Because of the difficulty of obtaining uniform slubbing of a fine count for the production of fine yarns from a single stripper ring doffer, a practice has developed of carrying out drafting on the mule in two stages. This is known sometimes as drawing and spinning. An investigation of this process was carried out, and some of the results obtained will be given here as they are relevant to the discussion of fiber behavior in drafting.

Briefly, the procedure, when drawing and spinning, is to apply a draft of about 1.5 in the first stage (drawing) with twist increasing during drafting, and then to twist the thread to a twist content about half of that which would be used if making yarn. This twist is in the opposite sense to that required in the final yarn. In the second stage (spinning), this thread—on cops—is placed behind the mule, and is given a draft during processing of about 1.3. While the mule is delivering the thread, the spindles take out the twist inserted in the first operation, and, generally, provide a little more in the opposite direction before drafting commences. Drafting then proceeds with the twist increasing rapidly, because the carriage travels at a comparatively low speed.

Some investigations were carried out on a Cheviot blend being processed in this way. Figure 19*a* shows a typical force-elongation curve obtained during the first stage, and Figure 19*b* a typical curve obtained during the second stage. In these figures force is plotted against an arbitrary time scale given by the recording apparatus, the zero on this scale representing the commencement of delivery of the slubbing or thread. Figure 20 shows similar results obtained with a Saxony blend.

In both cases the drawing operation showed a force pattern which rose to a maximum and then declined. The decline may be similar in nature and cause to that obtained in our single-spindle experiments, or it may be wholly, or in part, due to a slowing down of the mule carriage toward the end of its run. The patterns in Figures 19*b* and 20*b*, however, show quite different characteristics. The drafting force rose steeply to a maximum value very soon after drafting commenced and then remained substantially the same, with small fluctuations, until drafting was completed. Evidently fiber behavior was quite different in the two stages. This will be discussed in due course.

When the above experiments were carried out with the Saxony material, part of the same batch was condensed finer, and spun direct in one operation to the same yarn count. Measurements were then made of the irregularity of (*i*) the slubbing; (*ii*) the intermediate thread of the two stage process; (*iii*) the yarn from this process; and (*iv*) the yarn spun direct in one operation. The coefficients of variation were as follows: slubbing—15.6%; drawn thread—11.8%; drawn and spun yarn—18.6%; yarn spun direct—13.7%.

d. Irregularity of Drafted Thread

An investigation was carried out to see whether the findings obtained on the single-spindle apparatus, i.e. that as the thread was drawn it first became more uniform and then became rapidly more irregular after an optimum draft was exceeded, were true under actual mule spinning conditions.

On the single-spindle apparatus an initial length of 48 in. of slubbing was used, and individual lengths were drawn by various amounts into threads, which were removed and measured for irregularity. The irregularity of the parent length of slubbing was also measured.

On the mule, which must run continuously for satisfactory operation, it was not possible to measure the irregularity of particular lengths of slubbing before and after drafting; nor was it possible to stop the mule at various points and remove the thread for measurement. Instead, different drafts were provided by arranging different mule deliveries, and drafting each to 72 in. The mule was run continu-

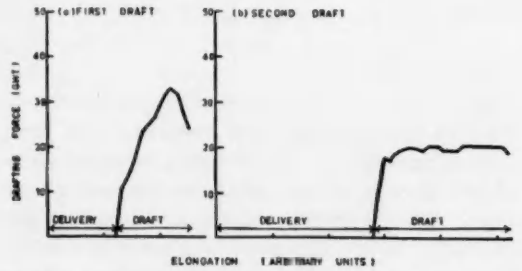


Fig. 19. Force-elongation curves in two-operation spinning on the mule. Cheviot wool.

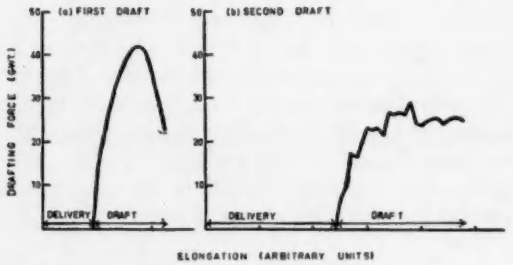


Fig. 20. Force-elongation curves in two-operation spinning on the mule. Saxony wool.

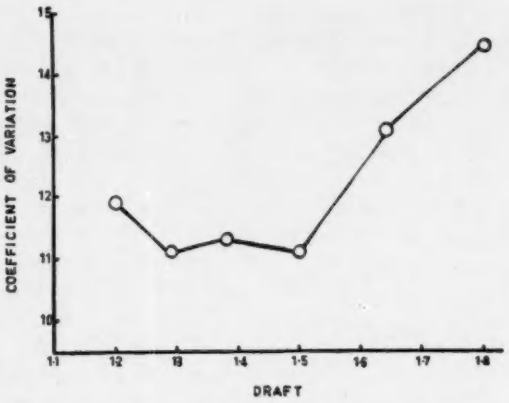


Fig. 21. Effect of draft on yarn irregularity on the mule. Cheviot wool.

ously and the material, drafted as required, collected as yarn.

The following deliveries were arranged to draft to 72 in., values of draft being given in brackets: 60 in. (1.20); 56 in. (1.29); 52 in. (1.38); 48 in. (1.50); 44 in. (1.64) and 40 in. (1.80). The twist inserted in each yarn made varied with the count spun, the values of twist chosen being those judged suitable by the spinner for medium warp type yarns of the various counts. For each delivery of yarn produced, irregularity was measured from a randomly selected sample. Spot readings of weight per unit length were taken at 100 points, 1 ft. apart, from *each* of 12 crops, for *each* yarn. The coefficient of variation for each 100-ft. section was calculated, and the mean of the 12 values taken as the measure of irregularity for that yarn.

Figure 21 shows the results, irregularity of yarn being plotted against draft. It confirms that the way in which irregularity develops with draft on the mule is similar to that found on the single-spindle apparatus. The graph may be thought to be a little less precise in its indications than those obtained previously (Figures 7 through 9). It should be noted that in the earlier cases it was possible to make a comparison between the irregularity of a particular specimen of drafted thread and its parent slubbing, and to calculate a smoothing coefficient. This ability to compare the same sample before and after treatment reduces sampling errors. In the case of the mule-drawn material, measurements of the irregularity of each yarn are affected by long-term variations of a fortuitous nature which increase the error of each mean value considerably, and many thousands of readings of thickness would be necessary to reduce this and give a smooth curve.

Because of these sampling errors, the curve is not smooth, and the value of optimum draft for minimum irregularity is in doubt, lying perhaps between 1.3 and 1.5.

e. The Effect of Dyeing Treatments

These results supplement those of Section II(*h*). They are included here as they were obtained on a mule rather than the single-spindle apparatus.

A manufacturing friend reported that he was processing three lots of wool; one was white, one was the same wool dyed red, and the third the same wool dyed green. No particulars of the dyeing processes were available, these having been carried out by a commission dyer, but the white was spinning much the best, and the green was a very poor spin.

Bobbins of these slubbings were put on the mule fitted with the apparatus for recording drafting force, and a number of force curves obtained under exactly the same spinning conditions. The means of these are shown in Figure 22, where force is plotted

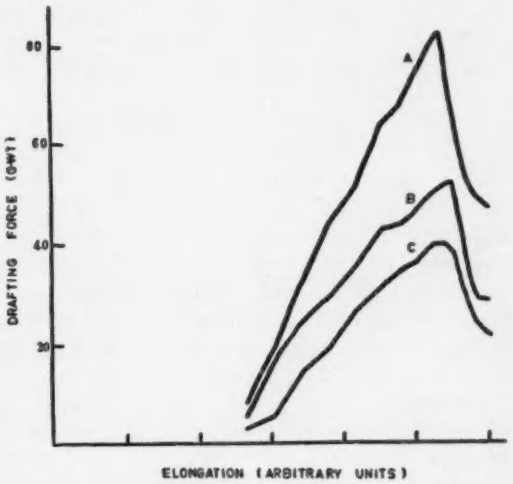


Fig. 22. Force-elongation curves on the mule for a wool with different treatments before carding.

A Undyed wool.
B Same wool dyed red.
C Same wool dyed green.

against the arbitrary time scale provided by the recorder. It would be unwise to read too much into these results, but it is interesting to note that the forces developed placed the materials in the order of merit found by the spinner, who based his judgment on ends down during spinning. The white thread was evidently the most coherent, and the green the least so.

IV. Discussion of Results

a. Introduction

The purpose of this part of the paper is twofold; first to put forward a hypothesis regarding the behavior of fibers during the process of spindle drafting, which will go some distance toward explaining the results obtained on both the mule and the single-spindle apparatus, and second, to draw attention to certain of the findings which may be of practical value and significance to the woolen spinner.

b. The Two-Phase Nature of Spindle Drafting

All the observations presented in this paper support the hypothesis that there are two successive phases of operation in spindle drafting, and that each is due to a different mode of fiber behavior.

The first phase is characterized by an increase of force with elongation, or draft, of gradually increasing proportions: it results in a reduction of slubbing irregularity. It does not produce any marked change in the weight profile of the slubbing beyond a tendency for longer term variations to be smoothed, and a reduction in the magnitude of the extreme deviations from the mean thickness. The second phase arrests the rise in force, and its continuance, where possible, produces a decline. The weight-profiles of the threads produced in this phase show large changes in the relative positions of groups of fibers compared with the parent slubbings. This phase is characterized by a rapid increase in the degree of irregularity as drafting continues. For some blends of fibers, in certain spinning conditions, the slubbings show unusually large changes of a slip-stick variety in one or more places during this phase; other blends show more moderate changes in more numerous sections.

The broken line in Figure 2 illustrates the division of the drafting operation into these two phases. The position of this line was determined from the estimated points of optimum draft in the corresponding figure showing the changes of irregularity with draft (Figure 7). The division between the two phases on the force-elongation curves cannot be precisely defined from the data given, but it can be fairly closely identified with regions following the points of inflexion of the curves. Such a region is presumably the closest statistical approximation possible to the division of the process into two separate parts; for a slubbing, however uniform it may be, is an aggregation of a number of groups of fibers, behaving in close association, but differing in their properties by reason of many random and fortuitous circumstances. Therefore, in postulating that one phase of fiber behavior is superseded by a different type of behavior associated with a second phase, we must not expect to find a very sharp line of demarcation between the two phases.

It is suggested that in the first phase of spindle drafting the fibers respond merely by stretching and straightening.

The rise in force upon elongation of the slubbing is very similar to that shown by the load-elongation curves for yarns, and even for fibers, whose characteristics are determined by changes in orientation of the individual components rather than by their slipping one over the other. Then again the high degree of correlation between the weight profiles of slubbings and threads which have been subjected only to limited drafts, suggests that their structure has not been disrupted. The gradual increase in the rate of rise of force in the early stages of this phase is caused by the varying degrees of extensibility of the different elements of the slubbing.

The way in which woolen slubbings are formed also supports the concept that stretching may take place, and that quite large extensions should be possible before fiber slippage will result; the lack of fiber orientation in woolen slubbing is well known. It may further be expected that if the fibers have a high degree of crimp this also will contribute to the stretching.

Further support for the suggestion that only stretching and straightening of fibers occurs during the first phase was provided by the tests carried out on the worsted roving. Figure 4 showed that for this material the first phase was complete after the relatively short elongation of 2.7 in. (5% extension). This results from the high degree of parallelization which the fibers in the worsted roving already had, and so there was little further opportunity for them to straighten further during spindle drafting and the first phase was soon completed.

It is interesting to note, however, that the *shape* of the force-elongation curve for this worsted roving was identical with that for the woolen slubbings. By adjusting the scales for elongation and force of the worsted material, the peak of its curve was made to coincide with the peak of the curve for a woolen slubbing; it was then found that the curves coincided up to this maximum. This suggests that the type of behavior is the same in both cases, and that its difference of degree is governed only by the difference in the nature of the two materials. The greatest difference of this kind is the amount of fiber parallelization in the two materials, hence it seems that the ability of fibers to straighten and orient themselves is the most important factor governing behavior during this phase.

That the relationship between force and extension is dependent upon twist content is shown by Figures 1, 2, and 3, and by the work previously reported on the mule. The more twist is applied to a slubbing the greater will be the force produced by any particular extension limited to this first phase, i.e., the greater will be Young's modulus.

That this stretching and straightening action could produce a more uniform thread would appear at first sight to be rather an unexpected result. However, once Young's modulus has been shown to be dependent on twist content the application of this result to individual lengths of the thread can provide the reason. Thin places will absorb more than their due share of twist and thick places less. The degree of extensibility of thin places will therefore be less than that of thick places, and differential, or preferential, stretching will result, leading to improved uniformity. In particular, small alterations in thick and thin sections at the extremities of the weight profile, produced by this differential effect, have great weight when the coefficient of variation of weight per unit length is calculated.

Up to a point the insertion of greater amounts of twist during this first phase might be expected to produce a greater differential effect, and so a greater improvement in levelness. It could further be argued that this differential effect should also be present when no draft is applied, contraction of the thin places being greater. This result has been noted.

The second phase of behavior commences once the thread has been extended to the point where the fibers are in a more parallel form, and, by virtue of their contacts and entanglements, cannot easily straighten or stretch any further. They then slip because the force to produce further straightening has begun to exceed that needed to produce fiber separation.

It should be noted that not all the fibers need to be in this form, only a certain number forming a core will be sufficient to prevent the remainder from straightening any further. It would further be expected that twist content, which governs the cohesion, would to some extent determine the point at which this slippage occurs, and it has already been remarked that the variation in the properties of different sections of the thread along its length will mean that the onset of the second phase will not be simultaneous at all points.

Extensions in this second phase therefore arise from fiber slippage in successive sections of the thread. These fiber movements are arrested in each section in turn by the transfer of twist from other sections, until a stage occurs when the over-all twist content is insufficient and rupture occurs. This fiber slippage relaxes the force upon the thread, and so a general decline in force is observed. This decline may be steady or quite erratic. In the latter case the extent of slippage is large in a few sections, which develop into very thin places; in the former case the number of sections where slipping occurs must be large, and the effect on weight profile less violent.

In both cases, however, the degree of irregularity is increased. This happens because the slippage at any point in the thread does not always stop when the average or desirable thickness has been attained. The incursion of twist from other sections takes time, and it appears that these slipping sections can become unduly thin before the repairing action of this extra twist takes effect. Examples have been shown where very thin places have been produced by slip, but the extra twist has succeeded in repairing them (stick), and the drafting force has temporarily increased again as a result.

All observations have been consistent with this two-phase interpretation of fiber behavior in spindle drafting, whether on the single-spindle apparatus, or on the mule itself. Some of these observations have been used to develop the argument; others may now be mentioned in support.

When a thread is being drafted, and is in the first phase of the process, it can be seen from the observation of projecting fibers that all sections of the

thread are rotating at the same rate. Twist which is being inserted is therefore being absorbed uniformly along its length. As soon as this phase is completed a considerable change takes place; the rotation of individual sections becomes spasmodic, some even rotating in the opposite direction momentarily, and there is continuous twist redistribution. It is suggested that this means that there is no fiber slippage and rearrangement during the first phase and that such movement can be consistent only with the second type of behavior noted in the second phase.

The experiments on two-stage spinning on the mule also support the same conclusions. During the first stage of drafting all the fiber straightening which can be achieved must be achieved. The result is that when the second stage of drafting is applied the force jumps almost immediately to a maximum; the force-elongation curve suggests that all the drafting which occurs subsequently is produced by fiber slippage, as one would expect. If this is so, one might expect the drawn thread after the first draft to be better than the original slubbing, which it was; but one would certainly expect to find a great deal of irregularity developed during the application of the second draft. The coefficient of variation increased from 11.8 to 18.6% during the second stage.

c. Practical Considerations

At first sight the most interesting practical consideration which seems to emerge from these experiments is the existence of an optimum draft for each blend, and the suggestion of a simple way of determining it. To carry out irregularity tests for a variety of draft conditions to determine this optimum would be a time-consuming and impracticable procedure, but if further work substantiated the validity of these results in a wide variety of cases, the problem would be reduced to the relatively simple one of taking one or two force-elongation records and choosing a draft corresponding to the point of inflexion on this curve, or rather beyond it.

Whether a test apparatus similar to the single-spindle apparatus described in this paper could be used to test blends in this way is not quite clear. There is a suggestion from the work done that the optimum drafts which are possible on the mule itself are greater than those found on the single-spindle equipment. This may be due to the different speed conditions applying on the mule. Then again it is clear that the effect of the plucking of the thread by the spindle is very important and would have to be taken into account. The high speed longitudinal vibration imparted by this effect would seem to facilitate fiber adjustment to the strains being applied by the moving carriage.

Another matter of practical importance, quite apart from quality of yarn produced, is the extent of drafting which is possible under given conditions, because this will be reflected in the number of ends down during spinning. Figure 2 shows how sensitive the extent of possible drafting is to twist content. In Figure 23 this extent of draft, in inches, has been plotted against the turns per inch of constant twist abstracted from Figure 2. This method of presentation shows that there is a fairly sharply defined twist content to ensure maximum extent of draft.

The results therefore show that there is some promise of being able to develop a simplified spinning technique, which could be a guide to the more complicated behavior on the mule. This would enable many practical matters, such as optimum draft, maximum possible extent of drafting, the effect of prior processes and spinning assistants, to be investigated. The results given here on the effect of previous wet treatments are not sufficiently complete to warrant discussion, but they do suggest a promising way of investigating the significance of certain fiber properties, and the extent to which their modification by scouring and dyeing processes, and the addition of oils, might be important in practice.

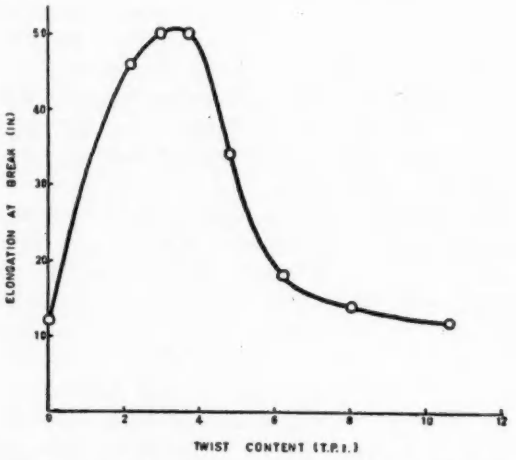


Fig. 23. Data abstracted from Figure 2 showing relation between elongation at break and twist content of thread.

A general theory of spindle drafting is practically nonexistent at the present time. If the suggestions made in this paper are acceptable, and stand the test of further investigation, they will give the woolen spinner a new standpoint from which to consider his practical approach to the problem of making a good yarn.

V. Acknowledgments

The authors would like to express their indebtedness to many people for making possible the work described: The Governors of the Scottish Woollen Technical College for providing the facilities; the International Wool Secretariat for a grant to one of us (J. A.), and further financial assistance for apparatus; to J. D. Williamson and G. V. Lee, our laboratory assistants, who helped considerably in carrying out the experiments; and to J. S. Nichol and J. C. Blake, students of the college, who carried out some of the investigations. To these organizations and gentlemen, we express our grateful thanks

Manuscript received March 2, 1956.

A Study of the Uster Dynamometer and the Scott IP-2

D. S. Hamby and W. C. Stuckey

School of Textiles, North Carolina State College, Raleigh, N. C.

THE steady development of quality consciousness and the potential economies for testing laboratories inherent in automatic single-strand testing machines have created a need for correlating the new-type testers with the conventional IP-2 type. Since the new instruments, or at least the Uster Dynamometer, employ a 20-in. gauge length of yarn and since the rate of loading on this type of machine can be varied, information on the differences, if any, that can be expected in results from the two instruments are important in maintaining mill standards.

Recent studies made at the School of Textiles, North Carolina State College, Raleigh, show an excellent over-all correlation between the two instruments. While yarn strengths using the 20-in. gauge length run slightly lower than for the 10-in. length used on the IP-2, the difference averages only 20 g. Differences in strength at various rates of loading were more pronounced.

The accompanying charts illustrate the differences found in the experiments.

Figure 1 charts the rate of loading on the IP-2 tester for various carriage weights. Figure 2 shows the rates of loading with various carriage weights at various rates of jaw separation of the rate-of-loading adjustment dial. The vertical line at the left of this chart indicates the theoretical setting on the Uster Dynamometer that will give a rate of loading corresponding to the IP-2.

Figure 3 illustrates the differences in strengths for various yarn numbers as affected by rates of loading on the Dynamometer. The higher rates of loading give higher strength values, and this tendency is more pronounced as the yarn count becomes heavier. One interesting point in addition to the change in strength as a result of tester speed is the change in slope when using different weights. The increase in slope with the increase in carriage weight follows the same general pattern as is shown in Figure 2. It would not be expected, however, that the slopes for the corresponding carriages in Figures 2 and 3 would be the same. The slopes shown in Figure 3

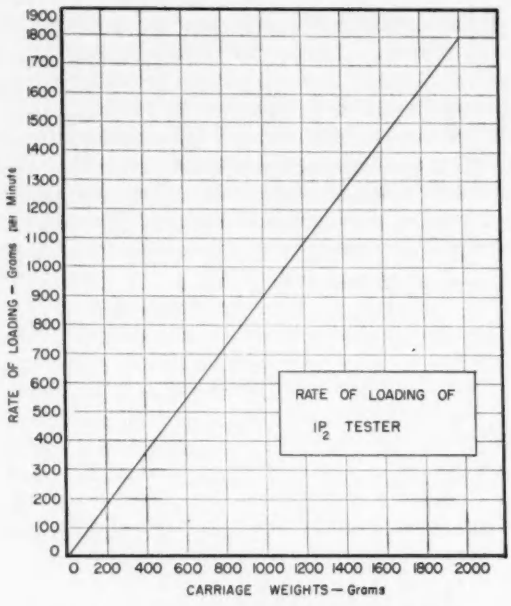


Fig. 1. The rate of loading for a Scott IP-2.

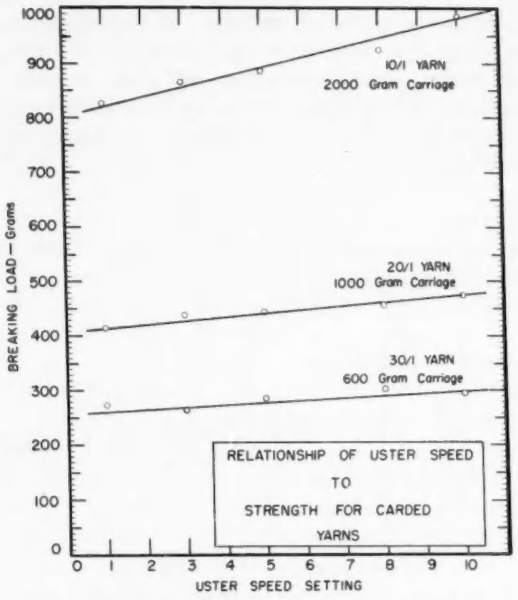


Fig. 3. The relationship between Dynamometer speed and carriage weight on the strength of carded yarns.

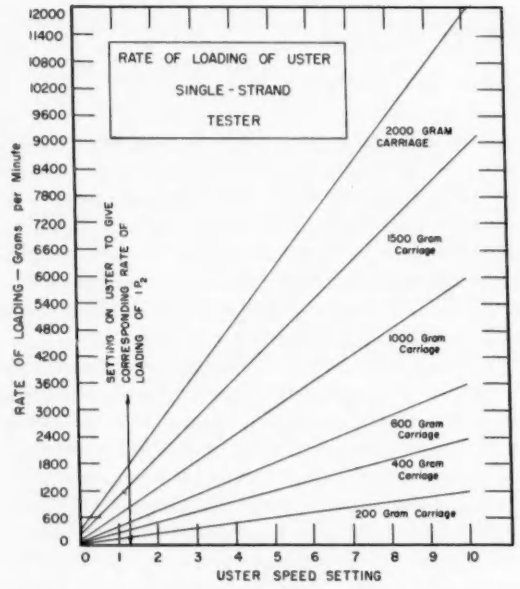


Fig. 2. The rate of loading for the Uster Dynamometer and the position number or speed which corresponds to the same rate of loading on the Scott IP-2.

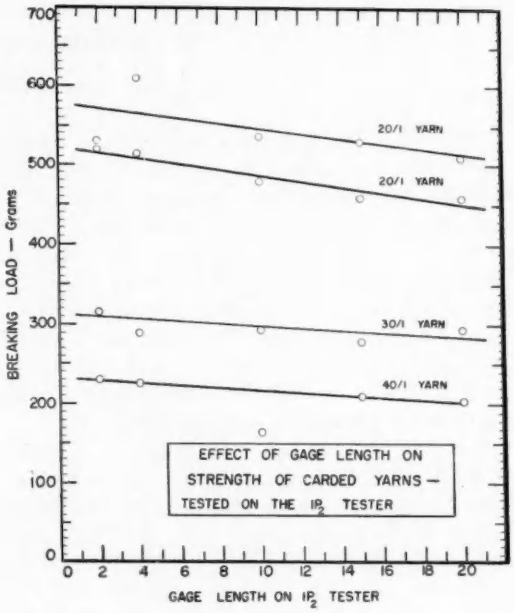


Fig. 4. An indication of the influence of test specimen length on strength.

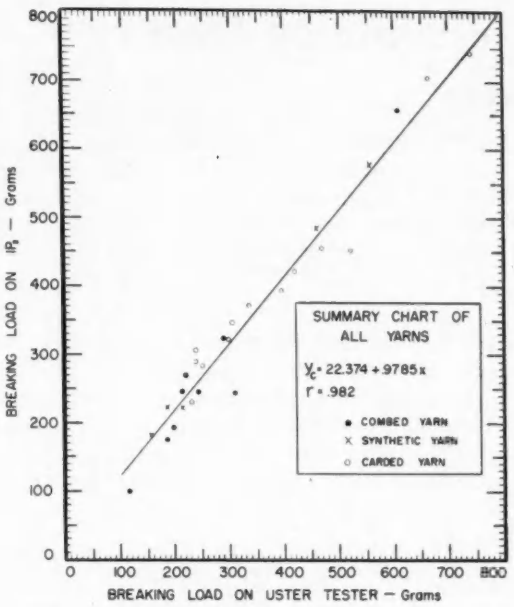


Fig. 5. A summary chart for carded, combed, and spun-synthetic yarns.

would also be influenced by rate of extension and time to break of the material.

Figure 4 shows the effect of gauge length on indicated yarn strength. As expected, the longer the length, the weaker the yarn appears to be. It clearly shows that the apparent strength is reduced by increasing the test specimen; however, this set of curves should not be taken as representative for all yarns since the slope or rate of change in strength varies not only with the specimen length but also with yarn evenness and type of yarn.

Figure 5 is a summary chart for carded, combed, and spun-synthetic yarns.

The Dynamometer speed for this particular study was set at position 5, and a 10-in. gauge was used on the IP-2. Studies were also made using a Dynamometer speed of positions 1, 3, 5, 8, and 10, and excellent correlation was obtained between the Dynamometer at these speeds and the IP-2; however, the slopes for these respective speeds varied from the ones shown in Figure 5. This was due in part to the influence of machine speed, as is shown in Figure 3, and also the fact that the rate of loading on the IP-2 remained constant. The slopes for the comparison between the testers varied from 0.97 to 1.2, depending upon the speed of the Dynamometer.

Figure 5 shows composite data for combed and carded cotton yarns and spun-synthetic yarns. As shown in this figure, there is no appreciable effect resulting from the type of yarn tested or the testing instrument used. This is substantiated by the coefficient of correlation of 0.98. The equation for the least squares line was found to be

$$Y_c = 22.374 + 0.9785X$$

Since the slope approaches 1 and the intercept is approximately 22, for a quick approximation of IP-2 strength from Uster data, it is only necessary to add 22 g. to the average Uster breaking strength.

It was determined that with a coefficient of variation ranging from 8 to 13, 75 to 100 breaks on the Uster would give a very reliable average for each of the cones; however, in this particular study, all averages used were for a minimum of 200 breaks, with most yarns being tested with 400 breaks.

The methods recommended by Uster Corporation for calculating the average strength, standard deviation and per cent coefficient of variation were found to be very reliable for the sample sizes used.

For all practical purposes, the two instruments can be considered as one. From a practical point of view, if the slope is considered as 1, 20 g. added to the average strength from the Dynamometer will give a reasonable estimate of the strength which would be obtained from a 10-in. specimen of the same yarn on the IP-2, if the Number 5 setting is used on the Dynamometer.

Acknowledgment

The authors are indebted to the seniors and graduate students in the Quality Control option at the School of Textiles, North Carolina State College, for their assistance in this study.

Manuscript received February 5, 1956.

The Characterization of Spinning Quality

J. F. Bogdan[1]

School of Textiles, North Carolina State College, Raleigh, North Carolina

Abstract

Four parameters characterizing spinning quality are described and determined for a set of yarn strength data by a method developed from one which was first proposed by F. T. Peirce. The skein break of any yarn number at any twist can be calculated for any fiber if these four parameters are known.

Introduction

F. T. Peirce [4] first presented the essence of his three-parameter theory of spinning quality in 1946. He stated that the strength of a yarn depends on three factors, the total strength of the fibers in the cross section which ruptures, the proportion of this which is realized in the breaking load, and the proportion which this weakest portion bears to the average along the yarn: fiber strength, cohesion, and regularity.

"These three factors are not an arbitrary choice among the many causes of strength and weakness; like the length, breadth and height of a box, they are three dimensions under which all the features affecting strength may be grouped and measured" [4].

This paper presents the author's interpretation of Peirce's proposed method for determining these three parameters for any textile fiber, with the addition of a fourth parameter which appears to be necessary in the study of spinning data for staple synthetic fibers because of their differing yarn-bulking and elastic properties.

Once, the spinner's life, if not simple, was at least predictable. Dealing with natural fibers procured from known territories, long experience taught him the effects on processing of subtle differences in familiar materials. Today, the myriad changes introduced by breeder and geneticist have made appraisal of even the natural fibers subject to much risk. New chemical fibers with their unlimited variations of surface characteristics, crimp, and finish preclude an accurate, easy estimate of their performance in manufacturing processes. Reliance must now be based on measurements if we are to choose fibers, predict their behavior, and understand and improve the characters that make for quality in textile raw materials.

The judgment of the spinner is most influential in the choice of raw materials, and it is the character of the yarn that is the most influential feature in the performance of a fabric. The spinning test has been, and is, an important and practical measure of fiber quality.

Spinning tests as made now depend on the skein strength at the maximum of the strength-twist curve. This is merely one point in a complicated function, the point at which increasing cohesion balances the decrease due to fiber obliquity.

If one must try to describe the shape of a curved surface with one point, this one is as good as any, but different fiber properties have different effects on fiber strength, drafting, and twist cohesion. Tendering by heat may lower fiber strength without affecting the way fibers cling or draft. Anything that affects cohesion changes the position of the maximum; the addition of a lubricant or of a colloidal silica will affect differently the response of fibers to twist without necessarily affecting fiber strength or drafting. Two fibers may have the same fiber strength and "drag," and one will be found better suited for spinning fine yarns because of its superior drafting properties, due to, say, the absence of short fibers. Various combinations of fiber strength, drafting, and cohesion may give a common maximum strength point.

Nor is the highest skein strength always the most desired quality. Broadcloth and hosiery yarns need softness of twist for luster and conformity; watertight or airtight fabrics require yarns of high regularity if they are to be impervious.

The positive components which contribute to yarn strength are fiber strength and fiber cohesion. The negative components which decrease yarn strength are yarn irregularity and fiber obliquity.

[1] Director of Processing Research.

Fiber obliquity is essentially a geometrical effect, but its coefficient appears to vary with the yarn-bulking and elastic properties of the fiber. The fiber obliquity parameter B, the drafting parameter F, the cohesion parameter T, and the intrinsic strength parameter P can be determined for any fiber from its yarn number–twist–yarn strength relationship, and will serve as the description of its spinning quality.

Once the four parameters for any fiber are known, the skein break for any yarn number at any twist can be calculated.

Definition of Terms

Figure 1 shows the geometrical significance of the four parameters of spinning quality.

The fiber obliquity effect is described by the value of B, which is dependent on the extent by which the strength-twist curve is depressed at high twists due to the twist angle at which the fibers lie in relation to the axis of the yarn. This parameter appears to be influenced by the yarn-bulking and elastic properties of the fiber.

The drafting parameter, F, describes the loss in yarn tenacity with increasing yarn fineness. Specifically, it is the number of units of breaking length per thread lost for each unit increase in yarn number fineness at high twists, with the breaking length corrected for fiber obliquity due to twist. It is influenced by fiber denier, fiber length, and fiber finish.

The ineffective twist parameter, T, is the distance along the twist multiplier scale at which the calculated twist cohesion curves originate. Its value may be either positive or negative. It is influenced by the surface characteristics of the fiber, by fiber crimp, and finish.

The intrinsic strength parameter, P, is the asymptotic value of breaking length per thread in hanks at high twist corrected for fiber obliquity and extrapolated to zero yarn number. It is influenced mainly by fiber tenacity.

If these four parameters are known for any fiber, the skein breaking strength for any number and any twist can be calculated.

Discussion

Two textile scales which are in common use are twist multiplier and count×strength product. The use of the twist multiplier allows a general classification of the relationship between twist per inch and yarn number. The count×strength product gives a level of yarn tenacity which is much less variable than the skein strength alone.

Twist Multiplier

The familiar twist multiplier is defined as the ratio of the turns of twist per inch to the square root of the inverse system yarn number.

$$\text{Twist multiplier, } M = \frac{t}{\sqrt{C}} \qquad (1)$$

Figure 2 shows the twist line on the surface of a yarn idealized as a cylinder. (Though this assumption is an over-simplification, with proper empirical correction, it serves very well to describe the influence of twist on yarn strength.) Here,

$$\tan \theta = \pi\, dt \qquad (2)$$

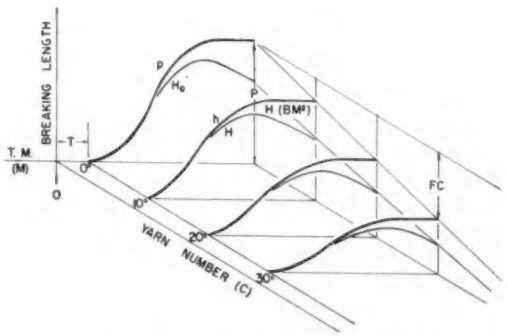


Fig. 1. Geometrical significance of the four parameters: F, T, P, B.

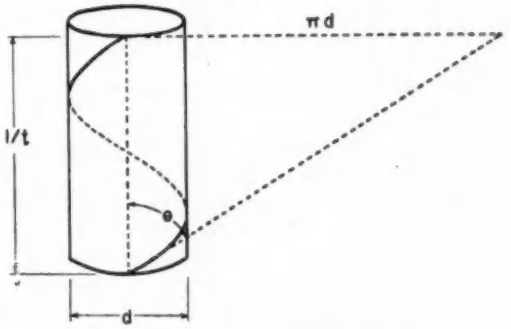


Fig. 2. Relationship of twist angle, twist per inch, and yarn diameter.

where θ is the angle between the twist line and the axis of the yarn, and d is the diameter in inches.

For the cotton yarn numbering system, the specific volume of yarn is

$$v = \frac{\pi d^2}{4} C(840)(36)\left(\frac{62.4}{12^3}\right)$$

$$= 858C\,d^2$$

$$d = \sqrt{\frac{v}{858C}} \qquad (3)$$

Then, from (1) and (2),

$$M = \frac{9.33}{\sqrt{v}} \tan\theta \qquad (4)$$

$$= \frac{29.3}{\sqrt{v}}\, dt$$

If we assume a constant specific volume for a yarn, then from (4),

$$M = K \tan\theta \qquad (5)$$

Count×Strength Product

Tenacity is force per weight, for textiles, usually expressed in units of grams per denier.

$$\text{Cotton system yarn number, } C = \frac{\text{hanks}}{\text{lb.}}$$

If length is held constant as it is in the skein break,

$$\frac{1}{C} \propto \text{weight}$$

$$\text{Tenacity} \propto \text{force} \Big/ \frac{1}{C} \propto \text{force} \times C$$

If the force is the skein break value in pounds, S, then tenacity is proportional to CS, the familiar count×strength product of break factor. The unit of CS is breaking length in hanks.

$$CS = \frac{\text{hanks}}{\text{lb.}} \times \text{lb.} = \text{hanks}$$

For example, in the case of a 20's cotton yarn number with a skein break of 100 lb., CS is 2000 and 2000 hanks of 20's yarn weigh 100 pounds. This length of 20's yarn hung from the end of a suspended skein would cause the skein to break.

The count×strength product can be easily converted to units of grams per denier. This is useful when it is desired to compare yarn tenacity as measured by the skein break with fiber tenacity.

$$\text{Yarn denier, } D = \frac{5315}{C}$$

A skein prepared for the skein break consists of 80 wraps, or 160 threads to which tension will be applied.

$$\text{Breaking length per thread in hanks, } H = \frac{CS}{160} \qquad (6)$$

$$\text{Grams break/thread, g.} = \frac{453.6\,CS}{160\,C}$$

$$\text{Yarn tenacity, g./}D = \frac{453.6\,CS}{(160)(5315)}$$

$$= \frac{CS}{1875} = 0.533\,\frac{CS}{10^3} \qquad (7)$$

A 20's yarn spun on the cotton system from 3-den., 2½-in. nylon, which yields a CS product of 3500, would have a yarn tenacity of 1.87 g./den. If the fiber tenacity is 4.2 g./den., then 45% of the fiber strength is realized in the yarn as measured by the skein break.

Slope of Count×Strength Product against Count

The decrease of count×strength product with increasing count is well known (Figure 3). The relationship is essentially linear.

$$CS = (CS)_0 - bC \qquad (8)$$

where CS is the count×strength product for yarn number C, $(CS)_0$ is the intercept on the CS scale of the plot of CS against yarn number, and b is the number of units of CS decreased for each increase in indirect system yarn number.

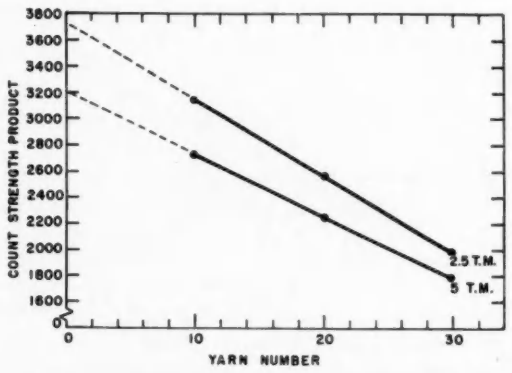


Fig. 3. Effect of yarn number on count×strength product.

Campbell [2] shows the following experimental values for this negative slope for different cotton staple lengths.

Staple length (in.)	Slope
$\frac{13}{16}$	25.1
$\frac{7}{8}$	23.1
$\frac{15}{16}$	23.3
1	21.2
$1\frac{1}{16}$	21.3
$1\frac{1}{8}$	17.4
$1\frac{3}{16}$	17.3
$1\frac{1}{4}$	15.9
Weighted mean	21.7

This mean value of 21.7 is used by A.S.T.M. Committee D-13 [1], to adjust the breaking strength of a cotton yarn to the specified number. The trend of decreasing slope with increasing fiber length is noted in the table above. Slopes other than 21.7 would give better adjustment of breaking strengths for cotton staple lengths shorter than 1 in. or longer than $1\frac{1}{16}$ in.

In the spinning of staple synthetic fibers it is noted that the magnitude of the negative slope of the *CS* product against yarn number is greater for coarse deniers than for fine. This is reflected in the inability to spin fine yarns from coarse deniers because of insufficient yarn strength.

Martindale [3] shows that the variance of a sliver or roving will increase by mere random probability as the number of fibers per cross section decreases. This slope of the *CS* line against *C* will be utilized to obtain a measure of the draftability of the fiber.

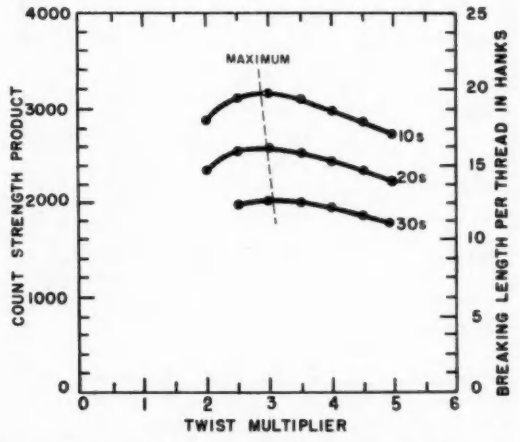


Fig. 4. Effect of twist multiplier on count×strength product or breaking length per thread.

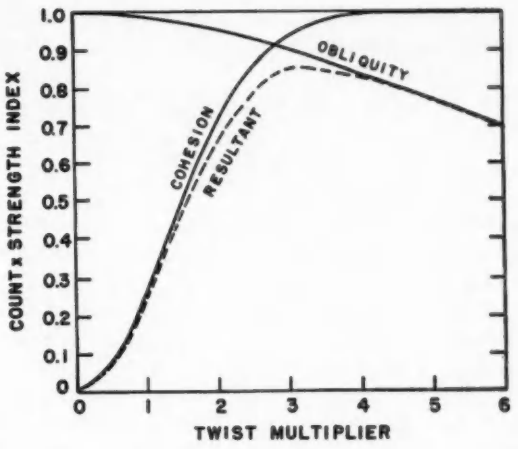


Fig. 5. Cohesion and fiber obliquity effects on yarn strength.

Fiber Obliquity

The plot of count×strength product against twist multiplier shows the characteristic sharp rise to a maximum and a more gradual falling off in strength such as shown in Figure 4. The rise is due to the increase in cohesion with twist; the drop, to the obliquity effect. The maximum yarn strength occurs at the point where increasing cohesion balances the decrease due to fiber obliquity (Figure 5).

Consider a fiber with a breaking strength of G lying in the direction of the hypotenuse of the triangle shown in Figure 2. Its contribution to yarn strength, g, is

$$g = G \cos \theta$$

The contribution of fiber weight, W, to yarn weight, w, is

$$w = W/\cos \theta$$

The force per weight is then

$$\frac{g}{w} = \frac{G}{W} \cos^2 \theta$$

Since $\cos^2 \theta = \dfrac{1}{1 + \tan^2 \theta}$ and twist multiplier, M, is proportional to $\tan \theta$,

$$\frac{g}{w} = \frac{G}{W} \cdot \frac{1}{1 + BM^2}$$

where B is the fiber obliquity parameter.

Replacing g/w with our yarn force per weight value, CS, we have

$$CS = \frac{(CS)_h}{1 + BM^2}$$

$$\frac{(CS)_h}{CS} = 1 + BM^2 \tag{9}$$

where $(CS)_h$ is the count strength product corrected for obliquity and CS is the actual count×strength product.

If the reciprocals of CS are plotted against M^2, as in Figure 6, and the best straight line is drawn through the points represented by high twists (where obliquity and strength curves coincide), the coefficient B can be determined by dividing the slope, a, by the value of the intercept on the ordinate, c.

$$1 + BM^2 = 1 + \frac{a}{c} M^2$$

$$B = \frac{a}{c} \tag{10}$$

The breaking length per thread corrected for fiber obliquity is:

$$h = \frac{(CS)_h}{160} = \frac{CS}{160}(1 + BM^2) = \frac{\frac{CS}{160}}{1 + BM^2} \tag{11}$$

$$= \frac{CS}{k} \tag{12}$$

$$k = \frac{160}{1 + BM^2} \tag{13}$$

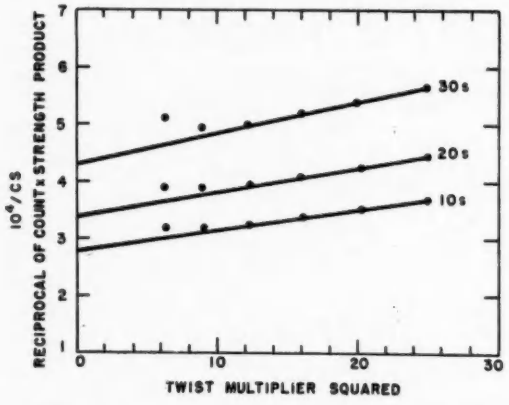


Fig. 6. Plot or reciprocal of count×strength product against square of twist multiplier for determination of obliquity effect.

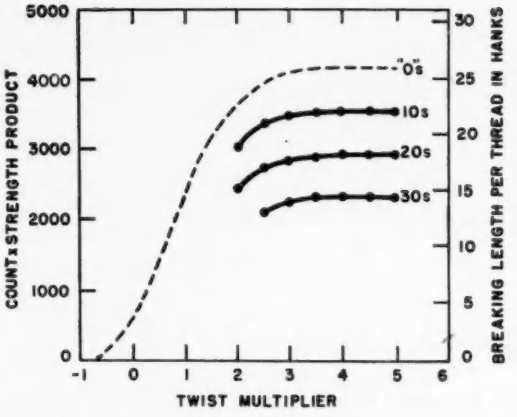


Fig. 7. Count×strength product or breaking length per thread corrected for obliquity.

Values of k can be calculated for each twist multiplier and used to correct count×strength products and slopes of count×strength products plotted against yarn number to units of breaking length per thread in hanks corrected for fiber obliquity.

$$h = \frac{(CS)_0}{k} - \frac{b}{k} C \tag{14}$$

$$= p - fC$$

At high twists p becomes P, the intrinsic strength parameter, and f becomes F, the drafting param-

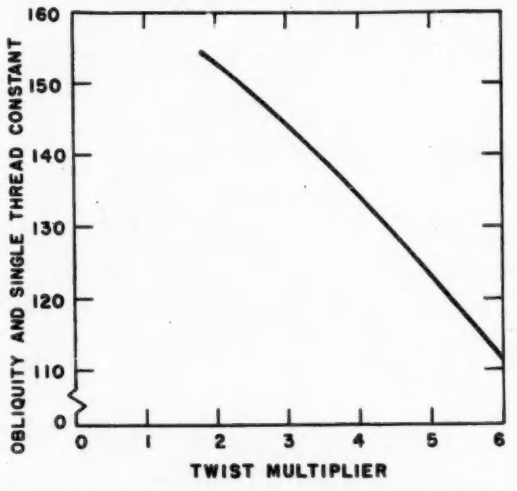


Fig. 8. Plot of constants for converting count×strength product to breaking length per thread corrected for obliquity.

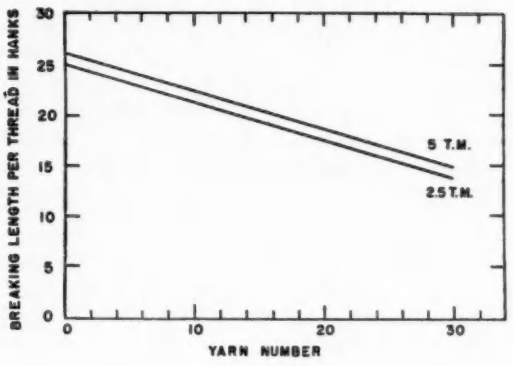


Fig. 9. Meaning of drafting parameter.

eter. The slope f is essentially equal to F over the practical spinning range (Figure 9), and no great error is involved in making this substitution to give:

$$p = h + FC \tag{15}$$

Fiber Cohesion

Plots of the breaking length corrected for fiber obliquity give curves of the form shown in Figure 7. These show the effect of increasing cohesion due to twist rising from zero strength at a common low twist to a constant maximum at high twists. The nature of this relationship is seen more clearly if each breaking length is expressed as a ratio to the maximum value in curves rising from 0 to 1 (Figure 12).

This curve can be fitted by the error function:

$$y = \frac{1}{\sigma\sqrt{2\pi}} e^{-z^2/2\sigma^2}$$

$$y' = \frac{y}{y_{z=0}} = 1 - \frac{p}{P}$$

where p is the breaking length per thread corrected for fiber obliquity and yarn number, and P is the asymptotic value of breaking length at high twists, the intrinsic strength parameter.

$$\log y' = -\frac{\log e}{2\sigma^2} z^2$$

If $A = \frac{\log e}{2\sigma^2}$ and $M - T = z$,

$$\log [1 - (p/P)] = -A(M - T)^2 \tag{16}$$

$$\sqrt{\log (1/[1 - (p/P)])} = \sqrt{A}(M - T) \tag{17}$$

where T is the ineffective twist parameter, the origin of the strength curve on the twist multiplier axis.

Values of $\sqrt{\log (1/[1 - (p/P)])}$ are plotted against twist multiplier as in Figure 10. The square of the slope of the straight line drawn through the points which represent those at which the corrected strengths were not at the asymptote gives the value of A. The intercept on the twist multiplier axis is the value of T.

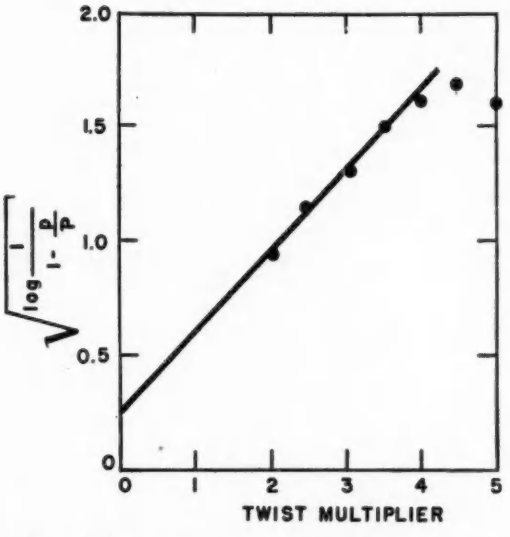


Fig. 10. Plot for determination of coefficient of cohesion curve equation and ineffective twist value.

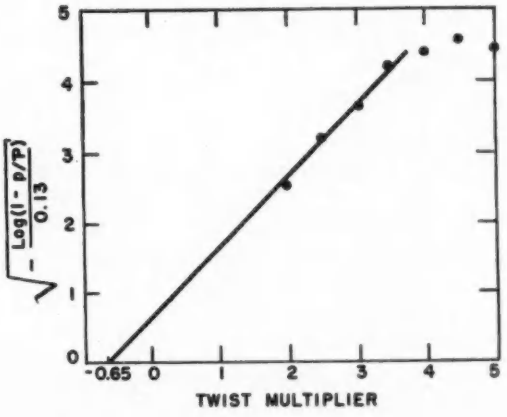


Fig. 11. Determination of ineffective twist value.

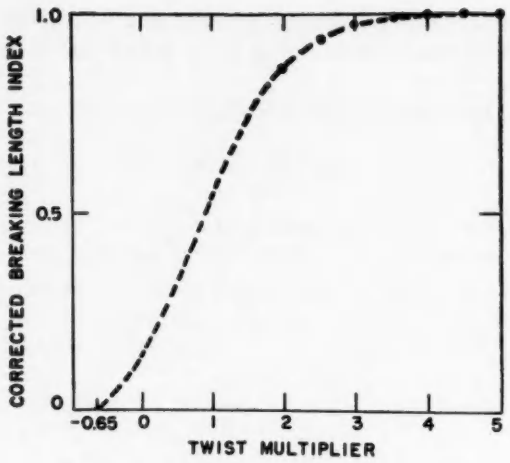


Fig. 12. Another method for determination of ineffective twist value.

It appears, at this writing, that a constant value of 0.13 for A will fit all normal cotton system spinning data. Then,

$$M = T + \sqrt{-\frac{\log [1 - (p/P)]}{0.13}} \qquad (18)$$

The plot of the radical values against twist multiplier (Figure 11) will yield T, the intercept of the straight line on the twist multiplier axis.

Calculation of Skein Break

If the four parameters are known, values for $(CS)_0$, the intercept of the straight line showing the relationship between count×strength product and yarn number, and b, the slope, can be calculated from:

$$(CS)_0 = Pk[1 - 10^{-0.13(M-T)^2}] \qquad (19)$$

$$b = Fk \qquad (20)$$

where

P = intrinsic strength parameter
k = correction for fiber obliquity and conversion to single thread breaking length, $\frac{160}{1 + BM^2}$, where B is the fiber obliquity parameter
T = ineffective twist parameter
F = drafting parameter
M = twist multiplier

Then the count×strength product for any yarn number and any twist can be determined by using Equation 8.

The equation for the skein breaking strength in pounds can be written:

$$S = k\left[\frac{P}{C}[1 - 10^{-0.13(M-T)^2}] - F\right] \qquad (21)$$

Analysis of Data

The data employed is the result of skein break tests rounded to nominal twist and yarn number on a series of yarns spun with three yarn numbers and seven twist multipliers from a lot of 3-den., $1\frac{1}{2}$-in. staple length, experimental synthetic fiber (Table I). Single-end break data can be treated just as readily.

The count×strength products are obtained and are plotted against yarn number for each twist multiplier (Figure 3). The best straight line is drawn through the points and the slope, b, and the intercept on the ordinate, $(CS)_0$, are calculated from Equation 8 (Table II).

The reciprocals of CS multiplied by 10^4 are determined (Table III) and are plotted against the square of the twist multiplier for each yarn number (Figure 6). The best straight line is drawn through the points at high twist. The fiber obliquity parameter, B, is the rounded mean of the ratios of the

TABLE I. Skein Break in Pounds

Twist multiplier	Skein break		
	10's	20's	30's
2.0	288	117	—
2.5	314	128	65.7
3.0	315	129	68.0
3.5	309	127	67.0
4.0	298	123	64.7
4.5	286	118	62.0
5.0	273	113	59.3

TABLE II. Count×Strength Product, Intercept at Zero Yarn Number, and Slope of *CS* Against Yarn Number

Twist multiplier	Count×strength product (CS)			Intercept $(CS)_0$	Slope (b)
	10's	20's	30's		
2	2880	2340	—	—	—
2.5	3140	2560	1970	3727	58.5
3	3150	2580	2040	3704	55.7
3.5	3090	2540	2010	3647	55.0
4	2980	2460	1940	3500	52.0
4.5	2860	2360	1860	3360	50.0
5	2730	2260	1780	3207	47.5

slope to the intercept of these lines (Equation 10). It is taken to be 0.012 for these data.

The count strength products may be corrected immediately by Equation 9 to give the results shown in Table IV. To convert to single thread strength and correct for fiber obliquity, values of k are calculated from Equation 13 and substituted in Equation 12 to give the values shown in Table V.

TABLE III. Reciprocal of Count×Strength Product and Constants

Twist multiplier (M)	M^2	$10^4/CS$ 10's	20's	30's
2.5	6.25	3.185	3.906	5.076
3.0	9.0	3.175	3.876	4.902
3.5	12.25	3.236	3.937	4.975
4.0	16.0	3.356	4.065	5.155
4.5	20.25	3.497	4.237	5.376
5.0	25.0	3.663	4.435	5.618
Constants				
Intercept, c		2.810	3.437	4.334
Slope, a		0.0341	0.0394	0.0514
$B=a/c$		0.0121	0.0115	0.0119

$B=0.012$

TABLE IV. Count×Strength Product Corrected for Fiber Obliquity

Twist multiplier (M)	$1+0.012\ M^2$	$CS(1+0.012\ M^2)$ 10's	20's	30's
2	1.048	3018	2452	—
2.5	1.075	3376	2752	2118
3	1.108	3490	2859	2260
3.5	1.147	3544	2913	2305
4	1.192	3552	2932	2312
4.5	1.243	3555	2933	2312
5	1.300	3549	2938	2314

TABLE V. Breaking Length per Thread in Hanks Corrected for Obliquity, and Slope against Yarn Number

Twist multiplier (M)	$\frac{160}{(1+0.012\ M^2)}$ (k)	$\frac{k}{160}$	Breaking length (CS/k) 10's	20's	30's	Slope (b/k)
2	152.67	0.954	18.86	15.32	—	—
2.5	148.84	0.930	21.10	17.20	13.24	0.393
3	144.40	0.902	21.81	17.87	14.13	0.386
3.5	139.49	0.872	22.15	18.21	14.41	0.394
4	134.23	0.839	22.20	18.33	14.45	0.387
4.5	128.72	0.804	22.22	18.33	14.45	0.388
5	123.08	0.769	22.18	18.36	14.46	0.386
6	111.73	0.698	—	—	—	—

$F=0.39$

The plot of these values is shown in Figure 7. It will be noted that the distance between like increments of yarn number is equal for any given twist multiplier. The slopes, b, are divided by the appropriate k value and the mean of these values is F, the drafting parameter, determined to be 0.39 here. Value of k may be plotted against twist multiplier as in Figure 8. For any twist multiplier, k can be read with sufficient accuracy for the purpose from the chart.

Values of p, the breaking length per thread in hanks corrected for fiber obliquity and extrapolated to zero count, are calculated by Equation 15 for each yarn number and twist (Table VI). The asymptotic value (26.2 hanks) is the intrinsic strength parameter P.

The value of T, the ineffective twist parameter, is obtained by Equation 17 or Equation 18 (Table VII, Figure 10 or Figure 11). It may be approximated very well by plotting on a scale from 0 to 1 values of p/P and superimposing over these points a curve drawn on transparent paper to the same

TABLE VI. Breaking Length per Thread in Hanks Corrected for Yarn Number

Twist multiplier	$\frac{(CS/k)+0.39\ C}{(p)}$ 10's	20's	30's	Mean	p/P
2	22.76	23.12	—	22.94	0.876
2.5	25.00	25.00	24.94	24.98	0.953
3	25.71	25.67	25.83	25.74	0.982
3.5	26.05	26.01	26.11	26.06	0.995
4	26.10	26.13	26.15	26.13	0.997
4.5	26.12	26.16	26.15	26.14	0.998
5	26.08	26.16	26.16	26.13	0.997

$P=26.2$

TABLE VII. Coefficient of Cohesion Curve and Ineffective Twist Value

Twist multiplier	p/P	$\sqrt{\log \frac{1}{1-(p/P)}}$	$\sqrt{-\frac{\log[1-(p/P)]}{0.13}}$
2	0.876	0.952	2.641
2.5	0.953	1.152	3.195
3	0.982	1.321	3.661
3.5	0.995	1.571	4.207
4	0.997	1.589	4.406
4.5	0.998	1.643	4.550
5	0.997	1.589	4.406
Slope, $\sqrt{A}$		0.36	
A		0.13	
T		−0.65	

scale, using the values given in Table VIII. These standard values are derived from Equation 16.

$$\log [1 - (p/P)] = -0.13M^2 \qquad (22)$$

The origin of the superimposed curve (Figure 12) gives the value for T.

TABLE VIII. Standard Values for Corrected Breaking Length Index Curve

Twist multiplier	p/P
0	0
0.25	0.0186
0.50	0.0721
0.75	0.1550
1.00	0.2586
1.25	0.3736
1.50	0.4901
1.75	0.6002
2.00	0.6980
2.25	0.7840
2.50	0.8460
2.75	0.8961
3.00	0.9324
3.25	0.9576
3.50	0.9744
3.75	0.9852
4.00	0.9917
4.25	0.9955
4.50	0.9977
5.00	0.9994

Values of $(CS)_0$ and b are calculated from Equations 19 and 20 (Tables IX and X). These can be plotted as in Figure 13 and values for a given twist multiplier read from the chart and substituted in Equation 8.

Substituting the values of the parameters in Equation 21 will give the skein break in pounds for a given yarn number and twist.

$$S = \frac{160}{1 + 0.012M^2} \times \left(\frac{26.2}{C} [1 - 10^{-0.13(M+0.65)^2}] - 0.39 \right) \qquad (23)$$

By differentiating S with respect to M and setting the first derivative equal to zero, an equation is obtained giving the yarn number for maximum strength in terms of twist multiplier and the four parameters

$$C = \frac{P}{F} \left\{ 1 - 10^{-0.13(M-T)^2} \times \left[1 + 0.299(M - T)\left(M + \frac{1}{BM} \right) \right] \right\} \qquad (24)$$

Substituting the values of the parameters obtained in our example,

TABLE IX. Calculation of Count×Strength Product at Intercept

Twist multiplier (M)	$M+0.65$	$0.13(M+0.65)^2$ (r)	Antilog $(-r)$ $(1-p'/P)$	$P[1-(1-p'/P)]$ (p')	Calc. $(CS)_0$ ($p'k$)
2	2.65	0.91292	0.1222	22.998	3509
2.5	3.15	1.28992	0.05129	24.856	3700
3	3.65	1.73192	0.01854	25.714	3713
3.5	4.15	2.3892	0.005769	26.049	3634
4	4.65	2.81092	0.001546	26.160	3511
4.5	5.15	3.44792	0.0003565	26.191	3371
5	5.65	4.14992	0.00007061	26.198	3224

TABLE X. Calculated Skein Break Compared with Actual

Twist multiplier	Intercept $(CS)_0$	Slope Fk (b)	Skein break in pounds and difference: 10's Actual	10's Calc.	10's Diff.	20's Actual	20's Calc.	20's Diff.	30's Actual	30's Calc.	30's Diff.
2	3509	59.54	288	291	−3	117	116	1	—	57.5	—
2.5	3700	58.05	314	312	2	128	127	1	65.7	65.2	0.5
3	3713	56.32	315	315	0	129	129	0	68.0	67.5	0.5
3.5	3634	54.40	309	309	0	127	127	0	67.0	66.7	0.3
4	3511	52.35	298	299	−1	123	123	0	64.7	64.6	0.1
4.5	3371	50.20	286	287	−1	118	118	0	62.0	62.2	−0.2
5	3224	48.00	273	274	−1	113	113	0	59.3	59.5	−0.2

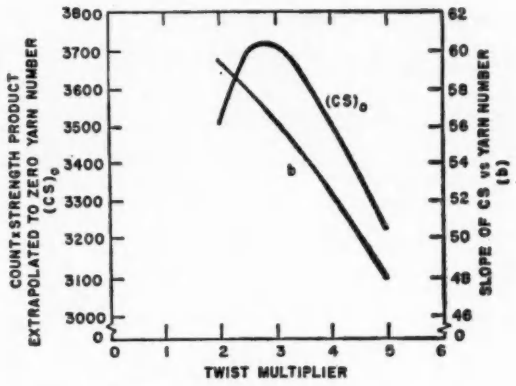


Fig. 13. Plots against twist multiplier of *CS* extrapolated to zero yarn number and slope of *CS* against yarn number.

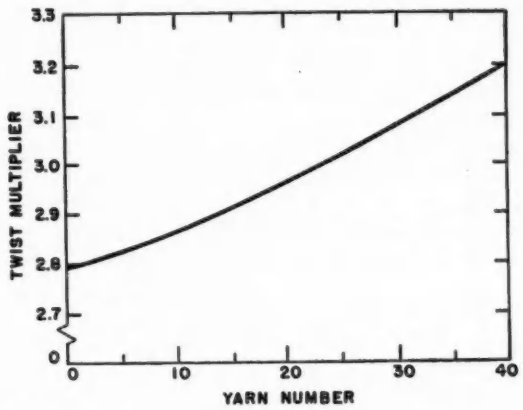


Fig. 14. Twist multiplier for maximum strength for a given yarn number.

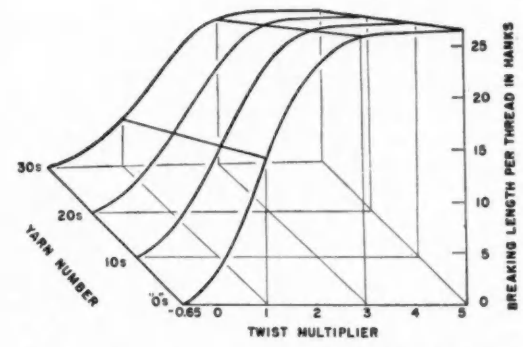


Fig. 15. Cubic diagram showing relationship of twist multiplier, yarn number, and breaking length corrected for fiber obliquity.

$$C=\frac{26.2}{0.39}\left\{1-10^{-0.13(M+0.65)^2}\times\left[1+0.299(M+0.65)\left(M+\frac{1}{0.012\,M}\right)\right]\right\} \quad (25)$$

Arbitrary values of twist multiplier, M, are substituted in Equation 25 to give the yarn number, C, for maximum strength (Table XI). Values of

TABLE XI. Yarn Number and Twist Multiplier for Maximum Skein Break

Twist multiplier (M)	Yarn number (C)
2.80	1.21
2.85	7.73
2.9	13.10
2.95	18.75
3.00	24.05
3.10	32.61
3.20	39.60

M are plotted against C (Figure 14), and the twist multiplier to be used to obtain maximum skein break for a given yarn number can be read from the chart.

The cubic diagrams, Figures 15 and 16, may help in understanding the geometric meaning of the parameters.

Approximation of Parameters with Limited Amount of Data

It is not necessary to have data as complete as those cited to get a very good approximation of the

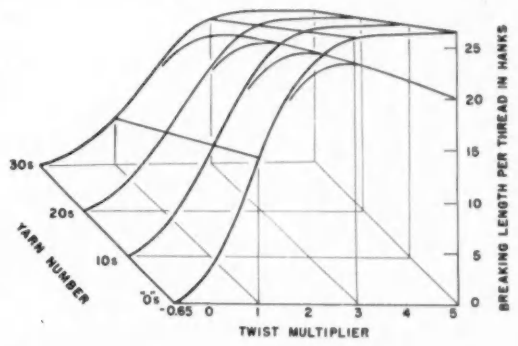


Fig. 16. Cubic diagram showing relationship between breaking length corrected and uncorrected for fiber obliquity.

TABLE XII. Approximation of Parameters with Limited Amount of Data

Twist multiplier (M)	CS		$10^4/CS$	$\frac{160}{1+0.012M^2}$	CS/k		$(CS/k)+0.387C$ (p')		p/P
	10's	20's	20's	(k)	10's	20's	10's	20's	
2	—	2340	—	152.67	—	15.32	—	23.06	0.884
4	2980	2460	4.065	134.23	22.20	18.33	26.07	26.07	0.999
5	—	2260	4.435	123.08	—	18.36	—	26.10	1.000

$b = 52.0$, $c = 3.41$, $a = 0.0411$, $B = a/c = 0.012$, $F = b/k = 0.387$, $P = 26.1$, $T = -0.7$.

four parameters. Data on only four yarns are treated in Table XII.

Most of the spinning is done on a median yarn number suited to the fiber denier and length. For the 3-den., 1½-in. staple fiber used here, a yarn number of 20's was chosen. One yarn is spun at a normal twist multiplier (M = 4), one at a low twist multiplier (M = 2), and one at a high twist multiplier (M = 5). This will allow us to define the form of the relationship between CS and twist multiplier so that the parameter B can be determined.

The drafting parameter, F, is obtained by spinning a coarser yarn at the same normal twist as the 20's. A 10's yarn number at a twist multiplier of 4 was tested.

The intrinsic strength parameter P is obtained by extrapolating the breaking lengths corrected for fiber obliquity at high twists to zero yarn number.

The ineffective twist parameter, T, is obtained by plotting the values of p/P against twist multiplier and superimposing over this the curve drawn on transparent paper from the values in Table VIII. The twist multiplier value at the origin of the curve on the twist multiplier scale is T.

The four points and their corrections are shown in Figure 17.

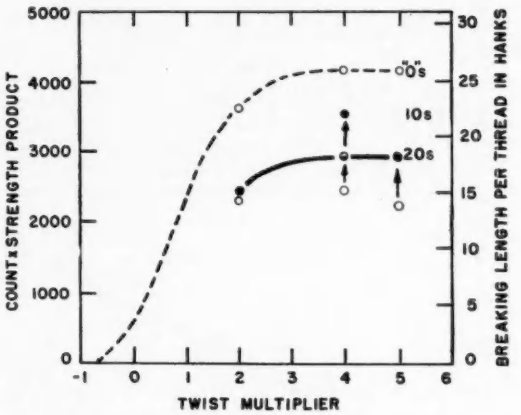


Fig. 17. Approximation of four parameters with limited amount of data.

Literature Cited

1. *A.S.T.M. Standards on Textile Materials*, D180–54T (1954).
2. Campbell, M. E., *U. S. Dept. Agr. Circ.* No. 413 (October 1936).
3. Martindale, J. G., *J. Text. Inst.* **36**, T35–47 (1945).
4. Peirce, F. T., *Textile Forum* **3**, No. 2, 8, 22–23 (May 1946).

Manuscript received February 10, 1956.

Random Tumble Pilling Tester

E. M. Baird, L. C. Legere, and H. E. Stanley

Textile Fibers Department, E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.

Abstract

A new type of tester for pilling tendency is described in which apparel fabric specimens are tumbled inside a rubber-lined cylinder in the presence of a small amount of cotton lint. The fuzz and pills formed in this process correlate well both in amount and appearance with those formed during wear on garments from the same fabrics.

I. Introduction

The evaluation of the pilling propensity of various textile fabrics has become of increasing importance, and a number of laboratories have developed instruments to measure this property. It is desirable that any test for pilling produce pills which correlate well with actual use performance, with respect to both the number and the appearance of the pills developed in the laboratory test. Furthermore, the test should be applicable to a wide variety of apparel fabrics without requiring changes in test conditions. If a test satisfies these requirements for a number of carefully wear-tested fabrics, it is reasonable to assume that the mechanism of pill formation is realistic, and a continuing satisfactory correlation between laboratory test results and actual use experience might be expected.

Since realism in appearance and structure of pills formed in the test was a primary objective in this work, it was felt that this goal could be most likely attained by a laboratory test which subjects the fabric to flexing and rubbing actions such as a garment receives in normal wear. Multidirectional rubbing was considered to be preferable to the regular, repeated motions used in several available pilling testers.

In order to provide a laboratory test in which specimens are pilled in this manner, a new type of pilling tester, referred to here as the Random Tumble pilling tester, has been developed. It is the purpose of this paper to describe the construction and operation of this tester and to report the correlation of results obtained on it with wear test results.

II. Description of Apparatus

The Accelerotor, an instrument developed by the American Association of Textile Chemists and Colorists, has been found useful in predicting end-use performance of fabrics, since it produces in the laboratory appearance changes which are very close to many of the effects that occur in actual wear. In the descriptive literature furnished by the manufacturer,[1] mention is made of the possibility that the tester might be used to measure the pilling tendency of fabrics. Tests with other devices such as a home-type tumble dryer have demonstrated that a random tumbling action, when coupled with a much milder rate of abrasion than that obtained in the Accelerotor, produced realistic pills. Our work indicates that by suitably modifying the Accelerotor and with a special technique, satisfactory pilling can be secured. We prefer, however, to use a unit that differs from the commercial Accelerotor in cylinder size, operating speed, and impeller design; and which employs a nonabrasive lining material, together with multiple specimens, in one chamber. For greater testing capacity, we have found it convenient to use an instrument which includes six such units with a common drive and control.

The Random Tumble pilling tester developed in this laboratory is shown in Figure 1. Test specimens are caused to tumble freely in a cylindrical chamber (5.75 in. inside diameter by 6 in. in length) by the action of two 4.75-in.-long impellers equally spaced on a horizontal shaft located at the axis of the cylinder and rotating at a speed of 1200 r.p.m. The inside wall of each cylinder is covered with a removable neoprene sheet packing liner approximately $\frac{1}{4}$ in. thick, which leaves a clearance of about $\frac{3}{8}$ in. between the end of the impeller and the liner

[1] Trade publication dated July 1954 of Atlas Electric Devices Co., Chicago, Ill., which manufactures the "Accelerotor." The Accelerotor is covered by U. S. Patent No. 2,749,740, issued to H. W. Steigler.

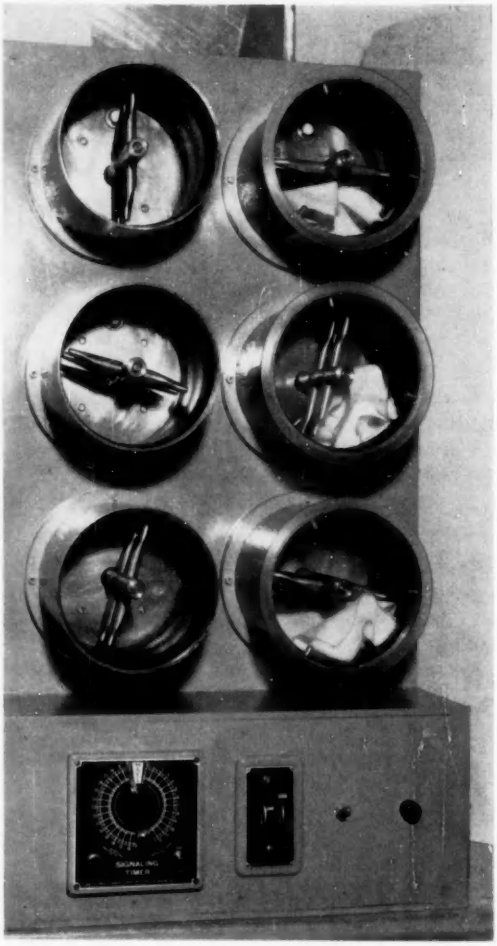


Fig. 1. Six-position Random Tumble pilling tester.

surface. In the tumbling action, specimens are constantly flexed and abraded multidirectionally by being rubbed against the neoprene liner as well as against the other fabric specimens.

The liner material is a very important part of the apparatus since (1) its frictional properties determine the rate of pill formation, (2) its durability must be such that it exhibits minimum change in frictional properties with running times of several hours, (3) it must provide an easily reproducible surface since the reproducibility of the test is directly related to the liner surface, and (4) it must not introduce static or other extraneous variables. Neoprene N-50 (manufactured by the Hamilton Rubber Manufacturing Co., Trenton, N. J.) is being used as the liner material at the present time.

III. Random Tumble Pilling Test Procedure

Test Specimen Preparation

Test specimen size, within limits, is not critical insofar as the essential principles of the test are concerned. Small specimens—less than about 3 in. square—do not tumble satisfactorily, however, and specimens greater than about 6 in. square are sufficiently bulky to cause difficulty by wedging between the impeller and the liner surface. Single specimens 5 in. square were tested in each chamber throughout the early development of the test. Recent tests, however, have shown that as many as three specimens, each 4 in. square, can be tested satisfactorily in a single chamber as long as all three specimens are of the same fabric. Exploratory tests, in which specimens of dissimilar fabrics were tested in a single chamber, revealed that strong interactions may occur under these conditions, resulting in nonreproducible results as a given fabric is tested with a series of different fabrics. Testing of multiple specimens in a single chamber is considered desirable because (1) a greater amount of fabric-on-fabric rubbing is obtained during a test than is the case with a single specimen, and this is considered by some to be highly desirable, (2) the capacity of the tester is effectively increased (thereby permitting more specimens to be evaluated), and (3) the presence of more than one specimen in a chamber assists in maintaining specimen agitation.

In preparing fabrics for testing, 4-in. square specimens are cut at a 45° bias from the fabric, and each edge is sealed with a light application of Duco [2] cement which has been diluted with acetone (2 parts Duco cement with 5 parts acetone). Sealing of the specimen edges is necessary in order to prevent them from becoming frayed and entangled with the impeller shaft during the tumble testing.

Preparation of Liners

In order to provide a liner surface which can be easily reproduced on new material, as well as on liners which have begun to show wear with prolonged use, liners are sanded with a vibrating sander, using 4/0 garnet paper, until a uniform matte sur-

[2] "Duco" cement is a product of E. I. du Pont de Nemours & Co., Inc.

face is obtained. After 30 min. of use on each side, it is necessary to clean the liners by a vigorous scrubbing. During early development of the test it was found that a brisk hand scrubbing with a stiff brush and scouring powder was sufficient to provide an acceptable reproducible liner surface. The time required for hand scrubbing, however, is prohibitive when a large number of tests are being run, and we have found that acceptable reproducible liner surfaces can be obtained when they are placed in individual nylon mesh bags and agitated in a domestic type washing machine for 15 min., followed by drying in a tumble dryer. Liners are conditioned at standard testing conditions of 65% R.H., 70° F. before being used for tests.

Periodically the liners are resurfaced by sanding. When "fugitive" finishes such as improperly cured silicone resins have been used, the finish may be transferred from the specimens to the liners during tumbling. This is evidenced by a slick, shiny appearance which accompanies a change in surface properties; the latter may occasionally be great enough to give low results and in such cases must be followed by sanding after each use. Other methods of cleaning liners after each test to reduce or eliminate the need for periodic sanding are being evaluated currently.

Addition of Loose Fibers to Test Chambers

As mentioned previously, a primary objective in the development of the Random Tumble pilling tester was to produce pills similar in appearance and structure to pills formed in wear. While it was found early in the development of this test that the expected ***number*** of pills could be formed on a test specimen by the Random Tumble technique, the pills were invariably small, tight, and generally unrealistic in appearance. Variations in test conditions of time, speed, and liner materials failed to correct this difficulty.

It was discovered, however, that the inclusion of a small amount of short length cotton fiber ("lint") in each test chamber during the test run produced very realistic pills. The cotton fibers became entangled in pills as they were formed during the course of a 30- to 60-min. test run, producing typical large lint pills which were essentially identical to pills formed on garments in normal wear. It has been repeatedly demonstrated that the inclusion of cotton lint in the test chamber will not cause pills to form on a specimen which would otherwise be free of pills; the cotton lint contributes only to the formation of large, more realistic pills.

Random Tumble pilling tests in which different fibers, including cotton, nylon, Orlon,[3] Dacron,[4] rayon, or wool, were added as the loose fiber component, revealed that cotton is by far the greatest contributor to the formation of lint pills. Dacron was found to cause slight lint pilling, while nylon, Orlon, and wool caused negligible lint pilling.

The quantity and length of the added cotton fibers affect the appearance, but not the number, of test pills. It has been determined by subjective evaluation of test specimens pilled in the presence of various amounts of cotton of various lengths that satisfactory results can be obtained with the present test conditions by adding to each chamber 50 mg. of 0.2-in.-long cotton fibers. While the presence of this quantity of cotton is required to permit formation of pills of realistic appearance, it should be noted that only a small fraction of the available cotton is actually entangled in pills.

Examination of a large number of garments which had been pilled in wear confirmed the importance of the role played by foreign fibers, primarily cotton, in the formation of large, objectionable looking pills. The presence of cotton in pills was confirmed by examining garments under an ultraviolet light in a dark room. Under these conditions cotton fibers which had been exposed to detergents containing optical brighteners (this includes most of the cotton in wearing apparel) were readily detectable by their brilliant fluorescence. Also, the presence of cotton in the majority of pills formed in wear has been confirmed microscopically.

Operating Conditions Currently Used

At the present stage of development of the Random Tumble pilling test, our preferred conditions consist of tumbling three replicate specimens for 60 min. at an impeller speed of 1200 r.p.m. in a chamber lined with a sanded and washed neoprene liner and containing 50 mg. of 0.2-in.-long cotton fibers. In order to randomize small differences between liner surfaces, test specimens are removed after 30 min. of tumbling and the liners are turned over so as to provide a "fresh" side for the remaining 30 min. of a test. At the completion of 60 min.

[3] Trademark for du Pont's acrylic fiber.
[4] Trademark for du Pont's polyester fiber.

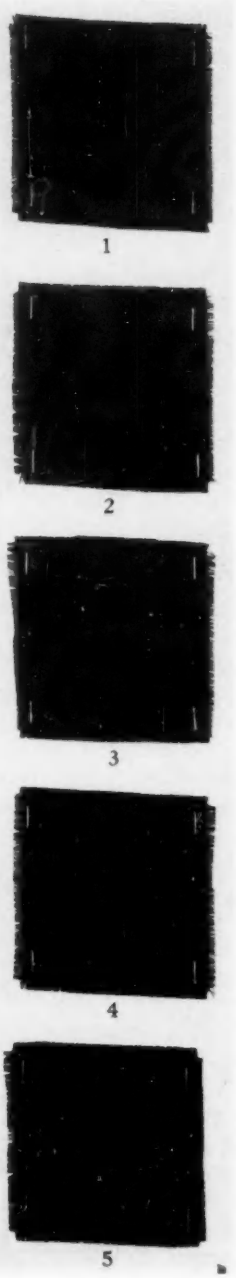


Fig. 2. Fabric standards of gabardine suitings showing scale of pilling acceptability ratings.

of tumbling, specimens are removed from the test chambers and subjected to a thorough vacuum cleaning to remove excess lint or loosely attached pills.

The same test conditions are used for all tests of apparel fabrics regardless of fiber type or fabric construction.

Evaluation of Test Specimens

Pilling test specimens may be evaluated by subjective comparison with standard specimens or photographs of such specimens, or they may be subjected to pill counts with the results being reported as pills per unit area. Pill counting was used to evaluate specimens during the development of the Random Tumble pilling tester because of somewhat greater resolution in detecting the effect of test variables on severity of pilling. Our experience indicates, however, that pilling of a fabric in wear should not be judged merely by the number of pills since other factors, including the size of the pills, the degree of color contrast between pills and fabric, and the amount of fuzz, all contribute to the acceptability of the fabric. Also we have noted that there is likely to be a wide range of actual pill counts assigned to fabrics whose acceptability is about equal, and that fabrics of equivalent pill count may differ greatly in acceptability.

We accordingly have used a system for rating the over-all acceptability of samples which has proved quite reproducible and rapid in use. Comparison "standards" have been established for various fabric types including tropicals, gabardines, worsted flannels, mill-finished worsteds, knit fabrics, and shirtings. In each fabric series pilled specimens have been chosen to represent characteristic examples of: (1) no pilling, (2) slight but tolerable pilling, (3) moderate pilling of borderline acceptability, (4) unacceptable pilling, and (5) extremely high pilling. The level of pilling at the various numerical ratings has been chosen to correspond to a similar rating system used by our field testing group in evaluating wear test garments. Figure 2 shows a set of standards for gabardine suitings.

Test specimens are evaluated by assigning to them a numerical rating of 1 to 5 which indicates their over-all pilling in comparison with the standards. Intermediate values such as 1.5 are used to indicate a level of pilling falling between two of the established standards. The average rating of at least three specimens, and generally six or nine specimens reported by two evaluators, is used as a basis for predicting the expected performance of a fabric in wear. The degree of correlation between laboratory tests and wear tests is discussed below.

IV. Discussion of Results

Wear Test Pilling Data

Samples of fabrics were collected which had previously been wear tested in statistically designed field experiments. These fabrics included a wide range of different weaves, fiber types, and fiber blends, i.e., gabardines, mill-finished worsteds, woolen flannels, tropicals, shirtings, and knit materials. The evaluation of worn garments for pilling performance were carried out using the subjective pilling acceptability ratings discussed in the previous section. We feel that the variety of fabric types, fiber types (and blends), and the range of pilling exhibited by these fabrics in wear are sufficient to establish with a high degree of reliability the correlation between laboratory test pilling and pilling in wear.

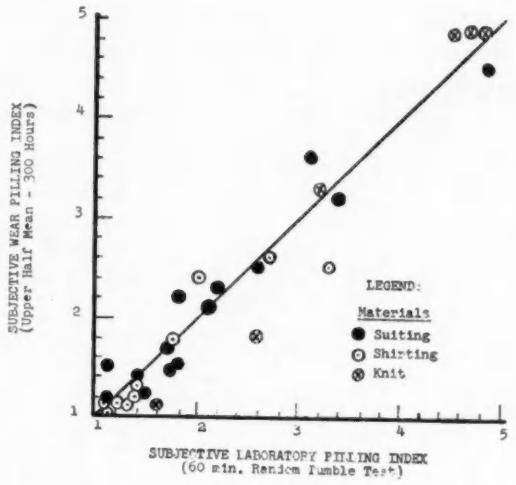


Fig. 3. Subjective laboratory pilling index correlated with subjective wear pilling index for suiting, knit, and shirting fabrics. Coefficient of correlation, $r = 0.96$ (significant for 99% probability). Regression line equation, $y = x$.

Correlation Between Laboratory and Test Results

Fabrics which pill in wear will generally show a considerable range of pilling, depending in part upon the nature and activity of the person wearing the garment; some garments will show relatively few pills and others many pills. It is theoretically possible, therefore, to establish laboratory test conditions such that test results can be used to predict either the over-all average pilling of a given fabric in wear, or the pilling to be expected in the high or low ranges of the wear pilling distribution observed for that fabric. In order to be on the conservative side in estimating a fabric's pilling propensity, it is desirable to have a test which will predict the pilling to be expected from the more severe wearers. The Random Tumble pilling test, when used as described above, has been found to correlate with the average pilling exhibited by wearers falling above the median. We have chosen to designate this value as the "upper half mean." Figure 3 shows the relation between wear pilling ratings of the upper half mean at 300 hr. of wear, and 60-min. Random Tumble pilling test ratings. Each of the 30 points in Figure 3 represents a different fabric. The plot includes 6 knit sweater fabrics, 2 tropicals, 5 gabardines, 5 mill-finished worsteds, 2 flannels, and 10 shirtings (pilling on only the body of the shirts was considered in establishing correlation). The correlation coefficient for this data is 0.96, which is significant for 99% probability. A regression coefficient of unity indicates a 1 to 1 quantitative relationship between Random Tumble test pilling and the upper half mean at 300 hr. wear. Additional data on several of the fabrics indicates a similar relationship between results secured in laboratory tests lasting 120 min. and the upper half mean after 600 hr. of wear.

The relationship between testing time and wearing time has not been completely investigated for the full series of fabrics used in obtaining the data reported in Figure 3. A previous regression analysis in which only 13 fabrics were used indicated that a linear relationship between testing time and wearing time might be expected.

In addition to the high quantitative correlation between laboratory test pilling and pilling in wear, we continue to find satisfactory agreement between the surface appearance of Random Tumble test specimens and worn garments. This is true not only for pilling, but also for other changes in appearance such as fuzzing, loss of cover, or "scuffing."

V. Conclusions

The Random Tumble pilling tester is a useful tool to predict in the laboratory the relative pilling performance of a fabric in wear. The primary advantages of the tester are: (1) a high degree of correlation between laboratory pilling and pilling for 300 hr. or more of wear for a complete range of fabric types and for a wide range of pilling, (2) pills formed on test specimens are similar in appearance and structure to pills formed in normal wear, even to the point of forming true "lint" pills, (3) all specimens are tested under the same test conditions, regardless of fiber type or fabric construction, and (4) the use of a multiposition tester provides sufficient capacity to handle the desired number of replicates in a reasonable time.

VI. Acknowledgments

The encouragement and assistance of Drs. R. M. Hoffman and A. G. Scroggie are gratefully acknowledged. Appreciation is expressed to E. E. Culpeper for carrying out the wear tests.

Manuscript received August 6, 1956.

Book Reviews

Review of Textile Progress, 1954. Volume 6, published by the Textile Institute and Society of Dyers and Colourists, December 1955. 586 pages. Price $5.50.

Reviewed by Helmut Wakeham

This volume is the sixth of a series of annual reviews of textile science and technology, covering literature appearing in the latter part of 1953 and 1954. It has been prepared by 33 distinguished contributors under the supervision of a joint committee from the two sponsoring societies headed by Chairman G. S. J. White.

All phases of fiber production and science, processing into fabrics, dyeing and finishing, and end-product application and evaluation have been covered in the 11 sections of the book. The organization of material is the same as that which appeared in Volume 5 with the exception that three new sections have been added. These are on the subjects of narrow fabrics, synthetic fibers in cordage, and bleaching of cellulosic fibers. Omitted this year has been the section on felts and nonwoven fabrics.

Contributors vary somewhat in their treatment of the subjects. Some appear to report only recent literature, whereas others are fairly selective and critical in their reviews. On the whole, however, the authors seem to have properly called attention to the more important developments without excluding at least some mention of minor matters. In many instances, such as, for example, in the summary of single-fiber tensile testers in the Fiber Physics Section, a comparison of several "competing" developments has been made. Such summaries are particularly useful to the technical reader and greatly enhance the value of the review.

The review material is presented in a readable form and appears to be well-documented with references to patents and the technical literature. A brief check of the references indicated satisfactory accuracy. There is a name index to the references which has about 3000 entries. A complete subject index containing about 2500 entries is also included.

A review of this kind brings home rather forcefully the very broad aspects of textile science and technology. The editors and contributors are to be congratulated for their thoroughness in producing such a comprehensive survey of the field and for their courage and persistence at undertaking the task on an annual basis. Since Textile Research Institute in the U. S. A. no longer publishes its annual "Survey of Textile Research and Development," the "Review of Textile Progress" is the only publication of its kind. It fills the very real need of bringing together in one volume the many technical facets of the textile world. At the unusually low price being asked, no one in the technical end of fiber production and utilization can afford to be without this book.

Testing and Control in the Wool Industry. Volume 3 in the Wool Research Series. Wool Industries Research Association, Leeds, England, 1955. 277 pages. Price 25s.

Reviewed by Gordon Marwine, Philadelphia Textile Institute.

This book is an excellent, well compiled text on testing of wool in all its phases. The volume is replete with tables, graphs, diagrams, and photographs of testing equipment. In addition to the test methods which are fully explained, the authors have included at the beginning of each chapter an introduction which acquaints the reader with the problems which he encountered in the specific tests discussed in the chapter. Sampling of fibers, fiber measurement, roving and yarn irregularity with the principles involved in its estimation, yarn strength, twist determination, testing of card slivers and slubbings for weight variation, strength, wear, thickness, air permeability, and water repellency are fully treated. In addition the authors have included interesting chapters on nomograms, mill experiments and operational research, determination of oil content, and shrinkage tests. Even though these tests are based on British practices and standards, the text should prove useful to Americans who are interested in testing procedures.

Quality Control Through Statistical Methods. Norbert Lloyd Enrick, New York, Modern Textiles Magazine, 1954. 72 pages. Price: single copies $5.00; in quantities of 15 or more, $3.50 each.

Specifically designed for textile mills, this manual is intended to furnish a practical and useful interpretation of modern statistical quality control as applied to textile processes from fiber to finished fabric, and to present typical procedures applicable to an effective quality control program. The material is drawn from a wealth of actual mill applications obtained during the author's consulting work and represents experience in more than 40 mills.

Generally the presentation is good although certain subjects could have been treated more completely. For example, in Chapters 7 and 8, more attention should be given to the sampling problems encountered in a quality control program in textile manufacturing. All in all this handbook should be useful to the practical man in the mill and to the student.

Textile Quality Control Papers. Vol. II. Edited by D. S. Hamby, Textile Division, American Society for Quality Control, 50 Church Street, New York, 1955. 238 pages. Price $2.00 (members) or $4.00 (nonmembers).

Volume II of Textile Quality Control Papers is comprised principally of papers presented at the 1955 Annual Conference of the Textile Division of the American Society for Quality Control. Papers from Sectional meetings and a few from independent sources are included. The 22 papers by individuals actively engaged in quality control operations, reports of task groups, and a bibliography contribute an up-to-date reference on many phases of quality control as applied to textile problems.

Textiles and Testing Course of Study. 2nd Ed., Hoboken, N. J., United States Testing Co., Inc., 1956. 96 pages. Price $2.75.

Originally prepared as a workbook for use in the Annual Textile Refresher Course given by the U. S. Testing Company, the second edition of Textiles and Testing Course of Study is available for purchase.

Recommended test methods, chemical and physical, for fibers, yarns, and fabrics are described, including analysis of fiber content and fabric performance tests. In addition, a brief description of fibers, both natural and man-made, is given. Manufacturing processes for yarns and fabrics are outlined. A great deal of useful information is presented, such as the new wool grade standards, recommended standard textile regains, and a list of reference sources. Under Theory of Weaving, there are 16 swatches covering basic weaves. The book is well illustrated. It is recommended as a useful reference for schools and textile personnel.

Study of the Control of Permeability of Nylon Parachute Cloth at High and Low Differential Pressures. Hamilton J. Bickford, Donald K. Kuehl, and Thomas L. Rusk, Jr., U. S. Department of Commerce, Office of Technical Services, Washington, D. C., Report No. PB 111855, 1955. 46 pages. Price $1.50.

This report, prepared by Cheney Brothers, covers work performed under a project contract with the USAF and administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center. The objective of the study was to obtain basic information on how the permeabilities, at high and low pressures, of a given nylon fabric could be independently controlled. This independent control, if it can be obtained by a fabric manufacturer, might permit the development of a fabric which will provide the parachute designer with a selection of properties and enable him to achieve improved parachute performance.

One type of fabric, a nylon cargo parachute fabric, was investigated. Twenty-four variations of the basic fabric were woven for this study. The experimental results indicate that the ability of the cloth manufacturer to vary the high-pressure differential permeability while retaining fixed low-pressure permeability ranges is practical within limits.

Physical and chemical tests, including strip-breaking and tongue-tearing strength, elongation, seam efficiency, and air permeability were made on the samples of finished cloth, and the results shown in tables. In six graphs are plotted values of air permeability versus pressure differentials. A special mathematical analysis of air permeability at ½ in. of Uster pressure differential and at higher differentials was made. The values are plotted on full logarithmic paper and show a linear relationship.

Principles of Mass and Flow Production. Frank G. Woollard, New York, Philosophical Library, 1955. 195 pages. Price $7.50.

Reviewed by Hillary Robinette, Jr., President, Robinette Research Laboratories, Inc., Ardmore, Pa.

The author, who has pioneered mass production and flow production techniques at the British Morris Motor Works, has in this volume laid down a series of 18 basic principles relating to the setting up of a flow production plant. The outline and philosophy described in this volume should prove useful to those working in production and to students of engineering economics. The book deals with the practical problems arising from the trend toward "Automation." One chapter is devoted to a discussion of the automatic factory of the future. The volume is well-illustrated with photographs made available to the author by American-European as well as British concerns.

To those engineers in the textile industry, charged with the responsibility of applying automation techniques, this book is recommended.

Man in Cold Environment—A Study in Physiology. Loren D. Carlson. Department of Commerce, PB 111716, Office of Technical Services, Washington, 1954, 161 pages. Price $4.25.

This monograph is designed to introduce to the new investigator the various physiological concepts and research techniques involved in studying man in the cold and to summarize and integrate this information for the experienced physiologist.

The author has selected material from recent published works as a basis for unified discussion. Among the subjects discussed are heat loss, data concerned with heat impact, circulation, metabolic adjustments, the related psychological studies and special aspects of aviation, clothing, and shelter. Included is an extended bibliography of some 700 references.

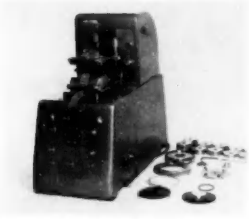
Wet-Cold I, Effects of Moisture on Transfer of Heat Through Insulating Materials. Alan H. Woodcock and Thomas E. Dee, Jr., Department of Commerce, PB 111639, Office of Technical Services, Washington, 1950. 21 pages. Price, 75 cents.

This report of a study by the Environmental Protection Section of the Quartermaster Climatic Research Laboratory, Lawrence, Mass., has recently been released.

An investigation was undertaken to (*a*) develop a theory accounting for the increased heat loss through wetted insulating materials, (*b*) observe effects of wetting on heat loss through selected textile materials, and (*c*) consider principles which may be utilized to minimize heat loss through clothing which is worn where wetting may be expected. Textile materials with widely different wicking properties were selected for the study.

The first part of the paper discusses some of the theoretical aspects, and the second part describes actual heat losses through several types of materials and interprets results in terms of the theory. Suggested applications to clothing are given.

The CSI Stoll Quartermaster
UNIVERSAL
WEAR TESTER



Model CS-22C

For measuring:

- **SURFACE ABRASION**
- **FLEX ABRASION**
- **EDGE ABRASION**
- **PILLING**

Reports by leading companies throughout industry have proven that the CSI Stoll Quartermaster Universal Wear Tester is a vital factor in both research and quality control. This multipurpose instrument will measure the resistance to surface, flex and edge abrasion of such materials as woven and knitted fabrics, napped and pile fabrics, hosiery, felt, non-woven and coated fabrics, yarns, threads, cordage, plastic films, rubber sheeting, leather, paper and many others.

ASTM Designations:
D1175–55T "Test for Abrasion Resistance of Textile Fabrics."
D1379-55T "Test for Abrasion Resistance of Textile Yarns."
D1375-55T "Test for Pilling Propensity of Textile Fabrics."

Federal Specifications:
CCC-T-191b Method No. 5300.
CCC-T-191b Method No. 5302.

As our name implies we also welcome the opportunity to work on custom design and manufacture of testing instruments of all types for individual and general needs.

CUSTOM SCIENTIFIC INSTRUMENTS, INC.
541 Devon Street **Kearney, N. J.**